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Transformation Roadmap from High to Low Temperature District Heating Systems
Annex XI final report

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International Energy Agency Technology Collaboration on
District Heating and Cooling including Combined Heat and Power

Annex XI final report

Transformation Roadmap from High to Low Temperature District Heating Systems

Project short title: Transformation roadmap

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Executive Summary

Background

The world is now planning and organizing a transition from the current fossil fuel based energy system to a future sustainable energy system based on renewables with greatly enhanced energy efficiency. This system transformation will of course also involve the current district heating (DH) technology, mainly developed within the fossil-based energy system, characterised by high temperature heat sources. However, the global district heating community has already performed similar system transformations twice before. Accordingly, the current best available district heating technology is labelled as the third generation. Consequently, the future sustainable technology generation should be labelled as the fourth generation of district heating technology.

This international research project has been focusing on identification of early and vital information about this transformation to a future fourth generation of district heating technology from previous technology generation shifts, current generation experiences, and early research attempts for this new district heating technology.

Every new technology generation for district heating has been characterized by lower distribution temperatures in the thermal grids, revealing that the temperature levels in these grids are important performance indicators. This conclusion is also valid for the new fourth generation, aiming at even lower temperatures in the thermal grids. Hence, the title of this project was chosen as ‘Transformation Roadmap from High to Low Temperature District Heating Systems’.

Research issues

The research work performed was based on seven identified research issues:

1. What experiences are available from previous shifts of technology generations for district heating?
2. What are the current temperature levels and the corresponding hydraulic situations used in district heating systems?
3. What are the possible solutions to reduce the current temperature levels used in district heating systems to a level close to the temperatures needed in the buildings?
4. What are the current temperature levels used in customer heating systems?

5 What are the possible solutions to reduce the current temperature levels used in customer heating systems while still satisfying heat demand with a correctly working heating system?

6 What temperature levels can be achieved in future district heating and customer heating systems and what are the corresponding low temperature heat sources?

7 What are the operational, technical and general conditions for concurrent operation of current and future parts of a district heating system with respect to their different temperature levels?

Conclusions

The conclusions provide the answers to the seven research questions:

1 What experiences are available from previous shifts of technology generations for district heating?

Answer: Hot water DH systems offer well-known economic and ecological advantages compared with steam DH systems. The dedicated shift from steam to water is accomplished either by installing new hot water DH systems indirectly connected to existing steam systems or by substituting existing steam systems with new water systems. Adding hot water circuits to a steam back-bone network can be implemented quite easily without significant impact on the steam system. Further transformation to low temperature DH is also possible: for example, return pipes in existing systems can be used as supply lines for low temperature DH.

2 What are the current temperature levels and the corresponding hydraulic situations used in district heating systems?

Answer: Annual average temperature levels in current systems are typically about 50-60 °C higher than ambient temperatures. These temperatures are elevated by about 10-15 °C compared with expected temperature levels because of temperature errors in distribution networks, customer substations, and customer heating systems. These errors increase the network return temperatures which in turn lead to higher supply temperatures, since the current hydraulic arrangements require a specific difference between supply and return temperatures. Use of indirect connections with heat exchangers in substations also incurs higher temperature levels.

3 What are the possible solutions to reduce the current temperature levels used in district heating systems to a level close to the temperatures needed in the buildings?

Answer: Three main strategies can be identified from the analysis of current temperature levels. First, all identified temperature errors in distribution networks, customer substations, and customer heating systems in current systems should be eliminated. Second, longer thermal lengths should be used in substation heat exchangers. Third, customer temperature demands in both new and existing buildings should be reduced, either by reducing the heat demand or by means of larger heat transfer surfaces.

4 What are the current temperature levels used in customer heating systems?

Answer: The research carried out in Switzerland revealed the only source of in-depth information of this kind. Here, the operational supply temperature for Space Heating (SH) is generally between 40 and 70°C. In new buildings equipped with underfloor heating systems, the operational supply temperature is typically between 25 and 35°C. The temperature required for Domestic Hot Water (DHW) preparation is mainly driven by the prevention of legionella generation (50-60°C is internationally considered as usual). DHW production often implies higher supply and/or return temperatures than SH because of legionella risks. Therefore the DHW production profile may influence the required supply/return temperatures of low temperature district heating networks.

5 What are the possible solutions to reduce the current temperature levels used in customer heating systems while still satisfying heat demand with a correctly working heating system?

Answer: Customer temperature levels can be decreased by optimizing the heat distribution in buildings. Potential ways to do this include buildings' envelope refurbishment to lower the heat demand; better supply temperature management; hydraulic balancing; use of variable-speed pumps; ensuring internal system components (eg thermostatic valves) are working properly. When carrying out envelope refurbishment, existing radiator sizes should be retained, and in new buildings, the use of small radiators should be avoided. Instantaneous production of DHW (without storage thus at lower temperature) is preferred, implying longer thermal lengths in substation heat exchangers.

Hydraulic schemes in substations should be conceived and adopted in order to achieve the lowest possible return temperature.

6 What temperature levels can be achieved in future district heating and customer heating systems and what are the corresponding low temperature heat sources?

Answer: The typical supply and return temperatures in district heating systems may in future be 55°C/25°C. In some areas with old buildings with low level of energy renovation temperatures of 70°C/40°C may be optimal in the coldest periods of the year. In areas with low-density heat use district heating with supply temperatures down to 35°C may be used in combination with local electrical supplementary heating of the DHW. The space heating system temperatures may be marginally lower by use of high performance heat exchangers.The following low temperature heat sources may be used for supply: waste heat from processes, deep geothermal heat, central heat pumps, solar heating plants with seasonal storage. Waste heat from incineration plants and backup power plants will contribute to the supply.

7 What are the operational, technical and general conditions for concurrent operation of current and future parts of a district heating system with respect to their different temperature levels?

Answer: It should be possible to elaborate effective strategies for concurrent operation to facilitate parallel use of current systems together with new low temperature parts with respect to operational, technical, and general conditions. The demand for concurrent operation will occur since new system parts will be introduced before the current system parts can apply the new low temperature technology. Some years will be required to lower the customer temperature demands in existing buildings by energy efficiency measures.

<u>Condensed Transformation Roadmap</u>

The condensed Transformation Roadmap can be expressed as:

1. Eliminate temperature errors in existing distribution networks and substations in order to make existing systems more efficient. This will reduce existing temperature levels.

2. Avoid these temperature errors in new network parts and in new substations.

3. Use heat exchangers with longer thermal lengths in substations for indirect connection of customer heating systems and closed hot water preparation. This will reduce the temperature differences between the warmer distribution waters and the colder fluids to be heated.

4. Reduce existing customer temperature demands by elimination of local temperature errors, reduction of heat demands by means of energy efficiency measures, and by installation of larger heating surfaces in radiator and ventilation systems.

5. New low temperature network parts in conjunction with existing systems can be connected by concurrent operation of these parts as secondary networks.

6. The long-term vision is to deliver heat to substations with a supply temperature of 50°C, while obtaining a return temperature of 20°C as annual average. However, the technical solutions for obtaining this low return temperature have yet not been defined.

Abbreviations

(in alphabetic order)

1GDH	First generation of district heating technology
2GDH	Second generation of district heating technology
3GDH	Third generation of district heating technology
4GDH	Fourth generation of district heating technology
BAT	Best available technology
CDH	Cold district heating
CHP	Combined Heat and Power
DH	District Heating
DHC	District Heating and Cooling
DHW	Domestic hot water
EHP	Euroheat & Power, Brussels
HTDH	High temperature district heating
IEA	International Energy Agency
IHEU	Instantaneous heat exchanger unit
LTDH	Low temperature district heating
MTDH	Medium temperature district heating
NTU	Number of thermal units (for heat exchanger design)
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

The temperature level for heat distribution in thermal grids is one of the key performance indicators for various generations of district heating systems. Compared to the previous technology generation, every new technology generation has actually distributed heat at a lower temperature level. The main reason for this general development is that the overall system efficiencies for renewables, heat recovery, storage, and distribution increase with lower temperature levels.

The future options for new heat supply include more use of low temperature heat sources such as solar heat, geothermal heat, flue gas condensation, and excess heat from electricity-intensive data centers, energy-intensive industrial processes, local bakeries, chillers for cooling etc. The common denominator for all these heat sources is that their profitability increases as the temperature at which they can be usefully harnessed decreases. Hence, the main economic driver for new district heating technology is better supply conditions for the expected future heat supply.

Furthermore, the distribution heat loss will also be reduced with lower temperature levels. Consequently, the inevitable temperature drop in the flow direction in supply pipes will also be reduced, giving lower exergy losses in future thermal grids.

1.1 Research issues

We have identified the following seven research issues for this project as:

1. What experiences are available from previous shifts of technology generations for district heating?
2. What are the current temperature levels and the corresponding hydraulic situations used in district heating systems?
3. What are the possible solutions to reduce the current temperature levels used in district heating systems to a level close to the temperatures needed in the buildings?
4. What is the current temperature levels used in customer heating systems?
5. What are the possible solutions to reduce the current temperature levels used in customer heating systems while still satisfying heat demand with a correctly working heating system?
6. What temperature levels can be achieved in future district heating and customer heating systems and what are the corresponding low temperature heat sources?

7 What are the operational, technical and general conditions for concurrent operation of current and future parts of a district heating system with respect to their different temperature levels?

These seven research questions have been divided into five subject areas shaping the five main chapters in this report:

- Previous generation shifts
- Temperature levels in district heating systems
- Temperature levels in customer heating systems
- Future temperature levels
- Concurrent operation of different generations

1.2 Limitations

District cooling issues are not included in this project, although several generations of district cooling technologies can be identified according to (Lund et al 2014).

Industrial heat demands and corresponding process heat demands are not included in this project, since they vary greatly.

In general, only system solutions providing complete heat delivery are considered. Hence, hybrid system solutions also including decentralised temperature boosters such as boilers or heat pumps in customer buildings are not considered in this project. These hybrid systems are often labelled as cold district heating systems (CDH) in many countries. However, one exception from this general limitation is the analysis of “ultra-low temperature systems” in section 5.3.3.

1.3 Definition of the district heating generations

The various appropriate time intervals for the four different generations of district heating technology are summarized in Figure 1 with respect to when these generations were used by early adopters, considered to be best available technology (BAT), or rejected as past technology.

1.3.1 First generation of district heating technology (1GDH)

The first commercial district heating systems were established in USA in 1880s, based on the results of steam distribution obtained 1876-1877 by Birdsill Holly in his pioneering Lockport experiments. This first generation technology was recognized as best available technology between 1890 and 1930, but is nowadays considered as past and outdated technology. However, this steam distribution technology is still used in two major district heating systems: the Manhattan system in New York and the city-wide Paris system. Both these urban areas in New York and Paris are extremely dense, giving very favorable conditions for low heat distribution costs. Paris has in fact the best conditions for efficient heat distribution in the whole European Union (Persson et al. 2011). Hence, both these systems can afford to use the first generation of outdated district heating technology in their current business activities.

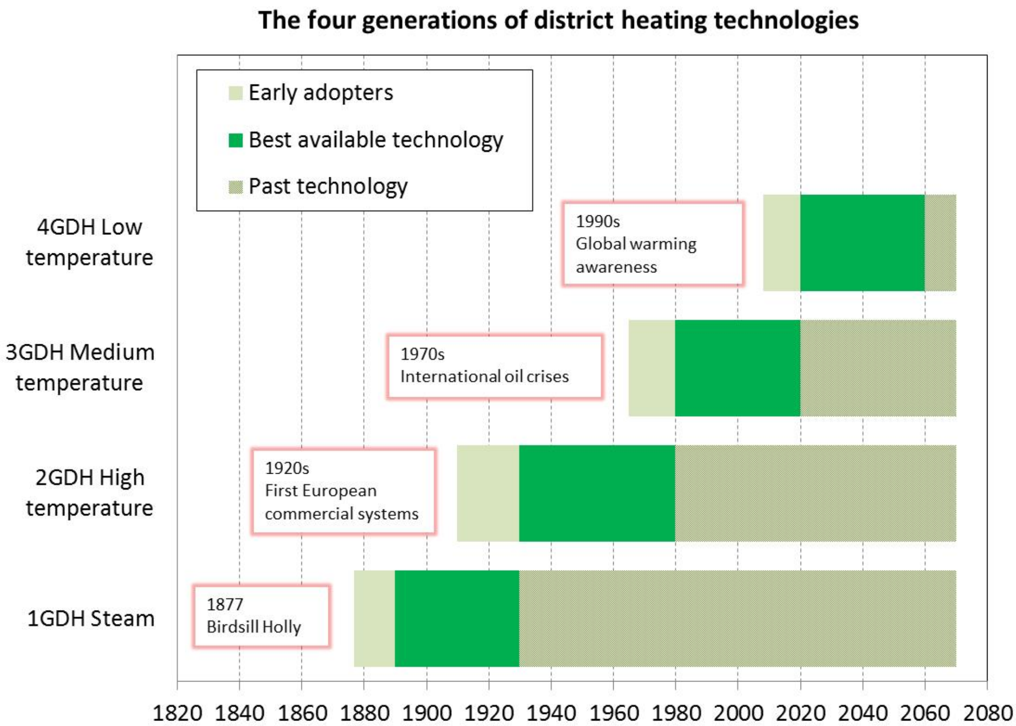


Figure 1. Overview of the four different technology generations of district heating.

1.3.2 Second generation of district heating technology (2GDH)

The first commercial European district heating systems were introduced in Germany in the 1920s, initially using steam distribution. But several German engineers questioned the choice of steam as heat carrier and advocated water as heat carrier in order to increase the system efficiency. These engineers became the early adopters of the second generation technology when they implemented their new ideas into new district heating systems. However, rather high supply temperatures were applied (above 100 °C), with a wide temperature difference between supply and return temperatures, in order that smaller diameter pipes could be used. This second generation technology was recognized as best available technology between 1930 and 1980.

The second generation technology was also applied in the USSR, when introducing and expanding district heating in the 1930s and 1950s. The Russian experiences and methods were later transferred to and utilized in China, when district heating was first introduced in the 1950s and 1960s.

1.3.3 Third generation of district heating technology (3GDH)

The two international oil crises in the 1970s created a higher interest in Europe for using district heating systems as a general tool for reducing the import dependence on fuel oil. This was especially the case in the three Nordic countries of Denmark, Sweden, and Finland. Engineers in these three countries advocated lower supply temperatures (below 100 °C) in order to improve the system efficiencies. Simultaneously, other productivity gains were obtained by using pre-fabricated and pre-insulated pipes together with pre-fabricated substations. This third generation technology has been recognized as best available technology since about 1980 and is currently utilized for expansion of all European district heating systems. The technology is also used in Russia and China for expansion of existing systems.

1.3.4 Fourth generation of district heating technology (4GDH)

The awareness of global warming emerging in the 1990s with creation of UNFCCC in 1992 and the Kyoto protocol in 1997 have created a renewed interest in district heating systems as a tool for substituting fossil fuels by using renewables and various low temperature heat sources.

Early adopters of low temperature district heating became the engineers that designed several pilot solar district heating systems in Sweden, Denmark, and Germany. These experiences were aggregated into the Marstal system in Denmark, when seasonal heat storage was also introduced into a European town-wide district heating system for the first time. The development of the Marstal system was supported by the Sunstore projects, financed by European research programs.

The conditions for and the corresponding five expected abilities of 4GDH have been defined by (Lund et al 2014). This definition paper was written by a group of researchers affiliated to the 4DH research center in Aalborg, Denmark with basic funding from the Innovation Fund Denmark. The five identified abilities are:

- the ability to supply low temperature district heating to space heating and hot water preparation
- the ability to distribute heat with low grid losses

- the ability to recycle heat from low temperature sources
- the ability to integrate thermal grids into a smart energy system
- the ability to ensure suitable planning, cost, and motivation structures.

The purpose of the development of 4GDH systems is to find a technology that can be harmonized for European conditions and that will support an expansion of district heating in European countries with low penetration of district heating. Hereby, this new district heating technology is expected to have the same role as 3GDH had for the expansion of district heating in the Nordic countries.

1.3.5 Cold district heating

All four generations of district heating presented earlier in this chapter have one typical common denominator. All heat is supplied into the distribution network and no heat is supplied at customer level to meet customer temperature demands. Hereby, the concept of district heating contains supply guarantees for both heat delivery and available capacity. The supply temperature in the distribution network is also always high enough to satisfy all local heat demands. These system solutions can be labelled as ‘warm district heating´.

By introducing some additional decentralized heat supply, a hybrid system is created that can use a lower supply temperature in the distribution network. This lower temperature is sometimes called an intermediate temperature, since it is lower than the actual customer temperature demand. The heat supply is then guaranteed by using local temperature boosters, such as boilers or heat pumps. This hybrid system solution is often called ‘cold district heating’ (CDH) in English, ‘kalte Fernwärme’ in German, or ‘kall fjärrvärme’ in Swedish, but other labels are also used. This CDH label includes all district heating system solutions requiring additional local heat supply in order to satisfy individual customer temperature demands.

Cold district heating systems can be apprehended as a complement to traditional warm district heating systems, when no suitable heat source with the required temperature is available in the neighbourhood.

Cold district heating systems may have a central heat supply from a low temperature heat source or even have no central heat supply at all. An example of the absence of any central heat supply is the Norwegian Fjordvarme concept, where fjord water is circulated in the cold water network (Fjordvarme 2016).

Central heat supply includes all heat sources that are warmer than ambient water, air, or ground, since the ambient temperature is the true reference temperature for all heating systems. Typical low temperature heat sources in cold district heating systems with some central heat supply are sea or lake water heat pumps, minewater, sewage water, industrial cooling water, and central solar collectors.

An early cold district heating system was the Bergen University system installed in 1995 (Stene et al 1995), where a central sea water heat pump delivers heat at an intermediate temperature to an uninsulated heat distribution system. The distributed water serves as both heat source and heat sink for local heat pumps providing heating and cooling to the university buildings. A similar system is also operated in Duindorp, Netherlands.

A typical minewater system is the Dutch Heerlen Minewater project (Verhoeven 2014) that was developed between 2003 and 2008 in a European Interreg project. The central heat source of minewater from an old flooded coal mine is distributed in the heat distribution system and the customer heat deliveries are supplemented by local heat pumps. Similar minewater systems are in operation in Bochum-Werne (EnEff Stadt 2016a) and Zwickau (EnEff Stadt 2016b) in Germany.

Similar cold district heating systems have also been proposed and analysed by (Lehtmets 2003, Zvingilaite 2012, Schwarzfeld 2015, and FLEXYNETS 2015). The FLEXYNETS project refers to these systems as fifth generation district heating systems, neglecting to consider the true distinction between warm and cold district heating.

According to the limitations in section 1.2, cold district heating systems are not a major research object in this report.

1.4 Generation characteristics

The four generations of district heating technologies identified so far are characterized not only by a certain temperature level (supply and return temperatures) having an impact on network heat losses but also specific greenhouse gas emission and primary energy factors (PEF) of the heat supplied differing due to the type of heat generators and heat sources integrated into the district heating system. Both greenhouse emissions and PEF also indirectly indicate the share of renewables and waste heat integrated into the DH system, and the share of fossil fuels in the heat generation, respectively.

1.4.1 Temperatures

When DH generations have been introduced by (Lund et al 2014) one (but not the only) characteristic was the heat carrier used in the network and its temperature. Although clearly defined temperature levels have been linked to the different generations as can be seen from Figure 2[1] temperature definitions are often indistinct, e.g. water temperature is either mostly over 100°C (2nd generation) or often below 100°C (3rd generation) but not strictly limited to 100°C.

Nevertheless, DH systems can be categorized by their temperature levels as follows: steam-based systems (1st generation), high-temperature water systems (HTDH, Tsupply > 100°C, 2nd generation), and medium-temperature water systems (MTDH, Tsupply < 100°C, 3rd generation).

4th Generation DH is characterized as low temperature DH (LTDH) with 30°C < Tsupply < 70°C. These low temperatures should be sufficient to meet end-user Space Heating (SH) and Domestic Hot Water (DHW) demands in central and north European climates while the typical supply temperature for peak load periods in Scandinavian countries could be 65-75°C thus exceeding the given maximum supply temperature by a small amount. Consequently (Dalla Rosa et al 2014) refers to these definitions but introduces a lower limit of supply water temperature of 80°C for 3rd generation DH.

In addition to the IEA DHC classification other categories are known as:

- Low-Ex DH systems (AGFW 2013) covering temperatures lower than 90°C.
- “Neutral” temperature levels (FLEXYNETS 2015) operated at 15 – 20°C. This kind of DH system belongs to the so-called cold DH as described already in Chapter 1.

Finally, it must be concluded that temperature definitions used to classify DH systems according to their temperature levels are not fully consistent. Figure 3 summarizes temperature levels used in the DH community so far.

[1] The Figure also illustrates new heat generation opportunities and increasing energy efficiency due to lower system temperatures.

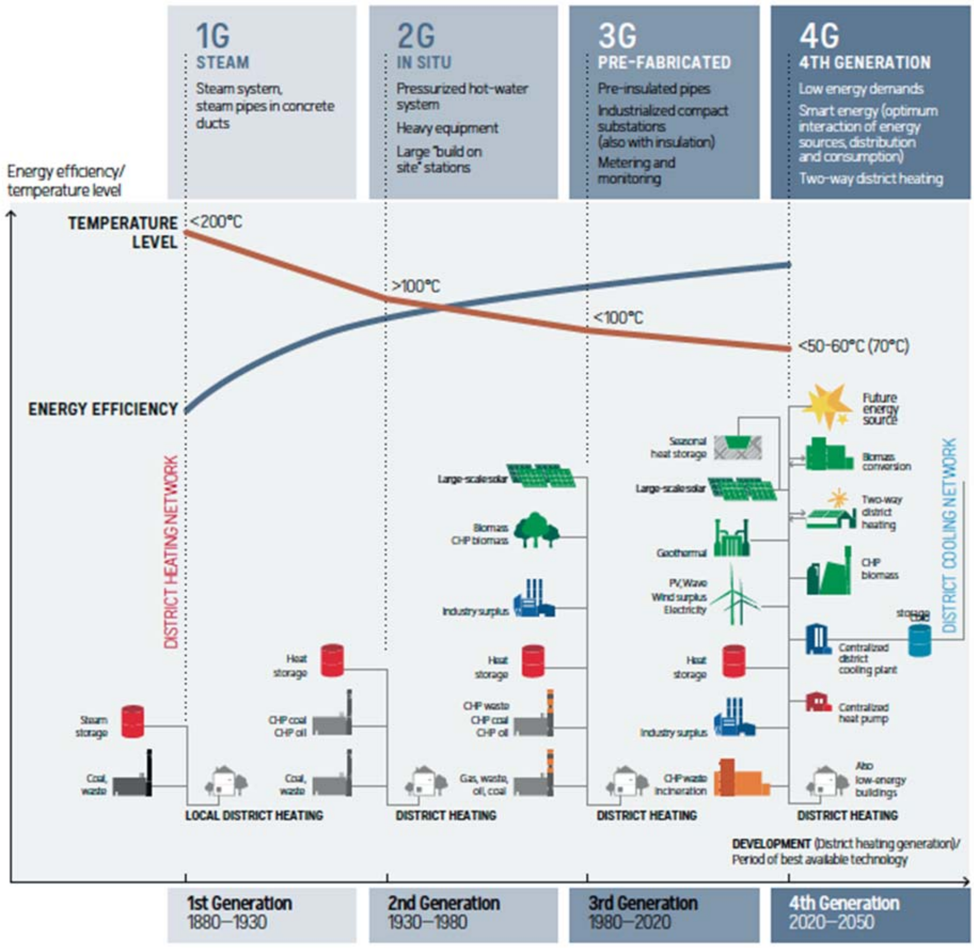


Figure 2. Historic development and heat generation characteristics of DH systems (Source: Aalborg University and Danfoss District Energy, 2014 found at (UNEP 2015); based on (Lund et al 2014))

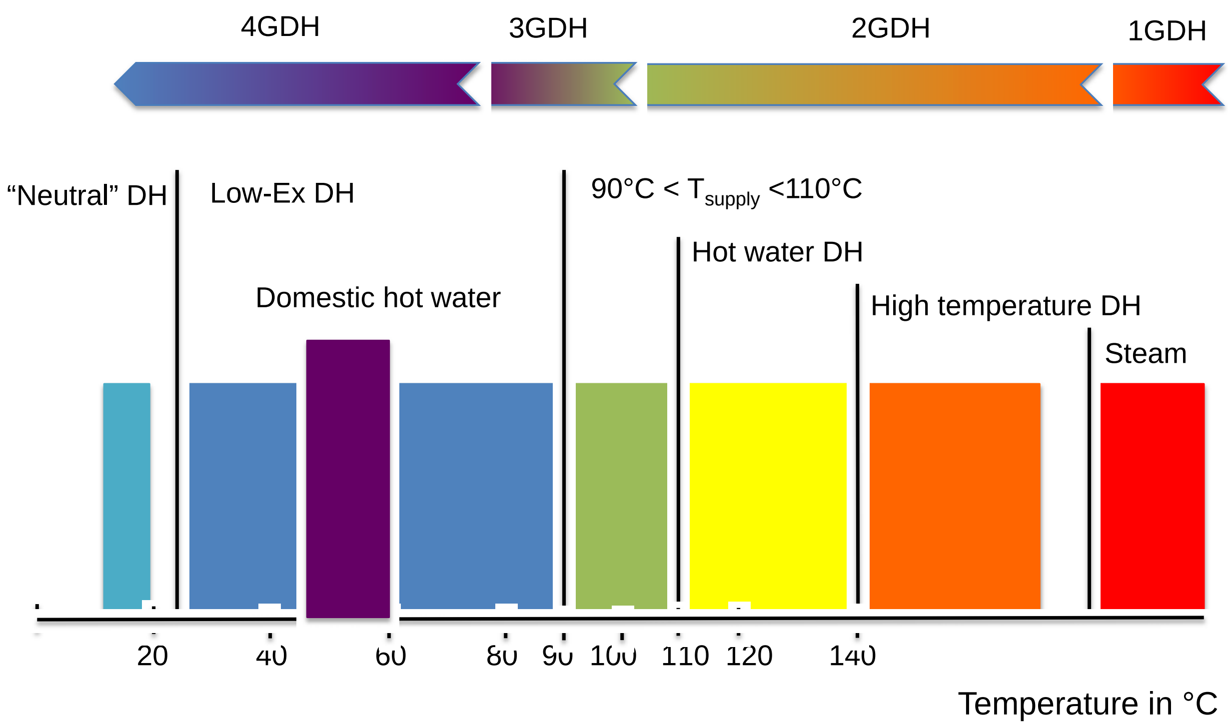


Figure 3. Temperature level definitions related to DH; modified illustration based on (AGFW 2013)

Besides these temperature levels, defining DH systems with some reference point is not easy. Often maximum water supply temperature in the design case is used as the peak reference temperature but there are also other options such as annual average temperatures or minimum allowed temperatures that could be used for the classification of DH systems. Partly according to (Dalla Rosa et al 2014) temperatures are defined as follows:

- *Supply temperature* [°C]: the temperature of the heat carrier in the media pipe carrying the heat from the heat source to the heat sink.
- *Return temperature* [°C]*:* the temperature of the heat carrier in the media pipe carrying the heat from the heat sink back to the heat source.
- *Continuous temperature:* the temperature at which the hot water network is designed to operate continuously. This temperature varies and normally depends on outside temperature as shown in Figure 4. It also depends on the availability of energy sources at higher temperature plus the overall economics.
- *Peak temperature:* the highest temperature at which a system is designed to operate occasionally. The low temperature DH concept includes the option of

increasing the supply temperature in peak load periods during the heating season to limit the dimensions of the distribution pipelines.

- *Annual average temperature:* the temperature calculated as an annual average of either the DH supply or return temperature.

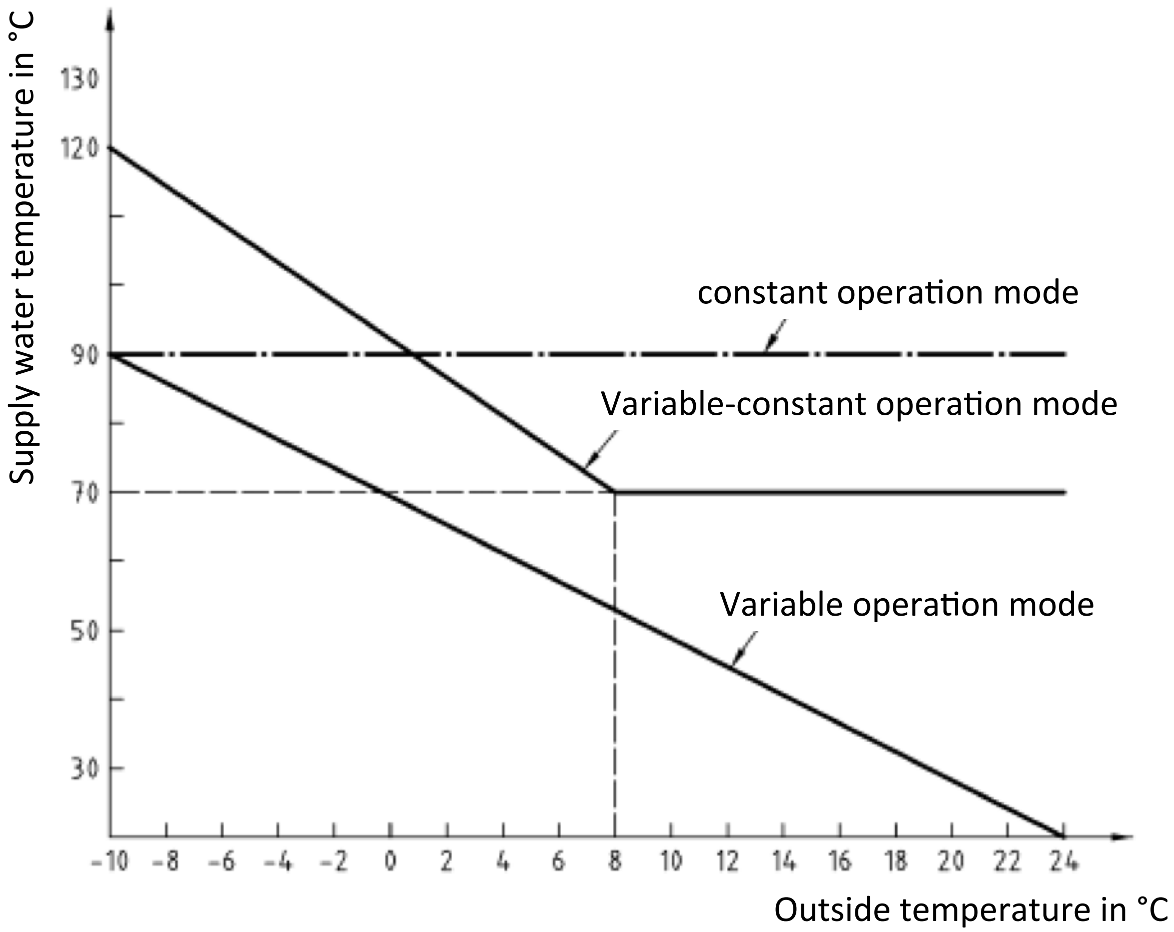


Figure 4. Different operation modes of a DH system depending on outside temperature compensation of supply water (according to (DIN 2003))

The temperature level of a DH system can also be used to evaluate the exergy of the heat supplied. The exergy of the heat supplied to the building should be as low as possible since space heating normally does not require high quality (i.e. high temperature) heat. The exergy loss of heat provided for a particular temperature drop (i.e. between supply and return temperatures) is calculated as follows:

$$\varepsilon = \frac{T_{\mathrm{m,\,DH}} - T_{\mathrm{m,\,amb}}}{T_{\mathrm{m,\,DH}}}$$

where $T_{m,\,DH}$ is average DH temperature

$T_{m,\,amb}$ is average ambient or reference temperature

The average DH temperature accounts for the temperature loss along the piping and is calculated by:

$$T_{m,\,DH} = \frac{T_{supply} - T_{return}}{\ln \frac{T_{supply}}{T_{return}}}$$

The following table comes from (Gong et al 2015). The reference temperature used to calculate ε here is annual average outside temperature.

Table 1. Typical exergy factors for heat supply into the DH systems at typical network temperature conditions. Annual average outdoor temperature (6…7°C) is used as the reference temperature

District heating system		T_{supply} (°C)	T_{return} (°C)	ε (%)
1GDH	Steam heating system (p=21bar, T_{supply}>100°C)	215	>200°C	42
2GDH	High temperature water system (T_{supply}>100°C)	120	70	24
3GDH	Medium temperature water system (T_{supply}<100°C)	90	40	17
4GDH	Low-temperature water system (T_{supply}=50-55°C)	50	20-25	9

1.4.2 Primary Energy Factors for heat

Both the sustainability of energy concepts as well as the impact of energy consumption on natural resources can be evaluated by estimating the non-renewable primary energy consumption. By allocating the consumption of an energy carrier to its corresponding primary energy consumption, the entire transformation process and energy chain is taken into consideration. Based on that DH can easily be compared to not only to any other energy carrier but also different generations of DH systems can be compared to each other. The concept of a PEF is described in (IEA Annex IX 2011).

Multi-output generation systems like cogeneration units or trigeneration of heating, cooling and electricity deliver more than one energy carrier. The energy carriers can be delivered to the same area (e.g. heat supplied by a DH system) or a different area or to another energy system (e.g. power supplied to the grid). If the energy carriers are delivered to different areas or different systems the exported primary energy is counted as a bonus (see Figure 3). (EN 15316-4-5)

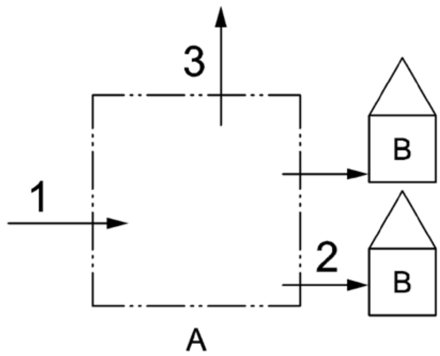


Figure 5. Multi-output district energy system with exported energy (CEN 2014); Keys: A-system boundary; B-energy consumer; 1-energy input to the system; 2-energy delivered from the system; 3-exported energy

The primary energy factor of the district heat is calculated according to Eq. (fP) given in (CEN 2014).

$$PEF = \frac{\sum E_{\mathrm{in;cr}} f_{\mathrm{P;cr}} - E_{\mathrm{exp}} f_{\mathrm{P;exp}}}{E_{\mathrm{del}}} \quad \text{(Eq. fP)}$$

where:

E_{in} energy content of energy carrier as input to the system;
E_{exp} energy that is exported to an external system or area;
E_{del} energy that is delivered from the system;
PEF primary energy factor of the district heating system;
$f_{P;cr}$ primary energy factor of an energy carrier;
$f_{P;exp}$ primary energy factor of the exported energy.

According to the formula (fp) the primary energy factor of the heat can be lowered by:

- increasing the share of energy that is exported,
- decreasing the primary energy factor of the energy carrier used for the input energies,
- increasing the heat delivered from the system.

While the first item is mainly related to conventional co- and trigeneration systems where electric power is produced as well as the heat and chilled water and delivered to an external client, the other two items are well addressed by 4GDH.

- Low temperature DH systems enable low temperature renewable and waste heat sources to be integrated. Normally primary energy factors allocated to these sources are very small or even zero.
- Low temperature DH will help to minimize heat losses from the distribution system. The energy efficiency of heat generators may also be improved. All in all there is more heat delivered from the system for a given input to the system.

Figure 6 shows example primary energy factors drawn from the Ecoheat4Cities project. Within this project an assessment and labeling scheme was elaborated that includes assessing the primary energy allocated to the heat supply. More information can be found at the project website. In Germany, AGFW is publishing primary energy factors of DH systems (AGFW 2016).

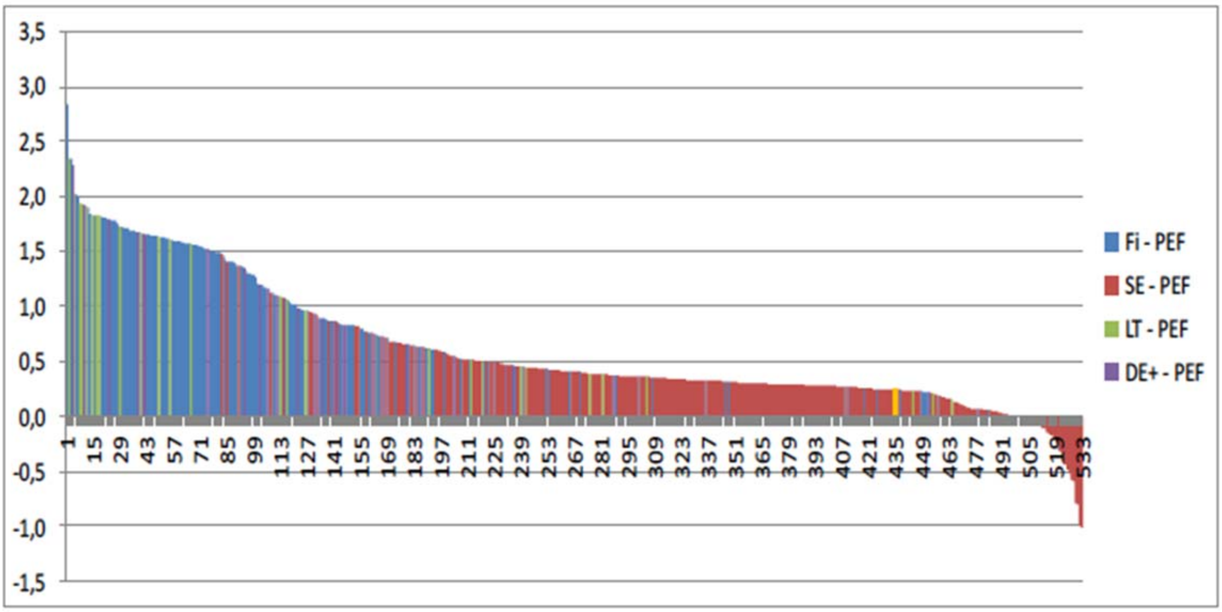


Figure 6. Non-renewable primary energy factor for different DH (EcoHeat4Cities 2012; Fi =Finland; SE = Sweden; LT = Lithuania; DE+= Germany)

1.4.3 DH efficiency and heat loss

The energy efficiency of the DH network can be expressed as the ratio of useful heat supplied to the total amount of heat generated. Here it is assumed that all the heat generated is fed into the DH network:

$$\eta = \frac{Q_{h,sup}}{Q_{h,gen}} = 1 - \frac{Q_{loss}}{Q_{h,gen}}$$

$$= 1 - q_{loss}$$

with $Q_{h,sup}$ heat supplied to end users in MWh/yr
(corresponding to E_{del} used in Eq. (fP))
$Q_{h,gen}$ heat generated in MWh/yr
Q_{loss} heat loss of the network in MWh/yr
q_{loss} percentage of DH network heat losses

The heat loss of the network depends on the temperature of both supply and return mass flow circulated in the DH system. Following the above equation a relative heat loss of q_{loss}=15% along the piping system leads to a DH network efficiency of η=85%. Lowering the temperature in the DH system will help to reduce heat losses and thus will improve DH network efficiency.

One should keep in mind that neither lower temperatures in the pipes nor larger temperature drops due to lower mass flow rates do not automatically represent a measure to improve network efficiency. Decreasing the heat supply and heat generation as consequences of energy efficiency measures in the building stock have to go hand-in-hand with reducing heat losses from the network. Otherwise DH network efficiency will deteriorate over the years. The transformation of the network can help to overcome this challenge.

1.5 Transformation strategies

In all, five different transformation strategies can be identified according to Figure 7. The future 4GDH technology can be directly be used in new systems connecting new buildings with low heat demands. Three ‘in advance’ situations occur when new buildings are connected in existing systems and when existing buildings are connected to new or existing systems. An ‘in advance’ situation appears when future 4GDH technology is used before all the benefits of 4GDH can be harvested. The fifth situation constitutes of all existing connections in existing systems.

This project aims to identify ideas and steps in these strategies for existing district heating systems. However, these ideas and steps may seem somewhat vague, since the final 4GDH technology for new systems has not yet been defined by anyone with respect to network, substation, and heat use designs.

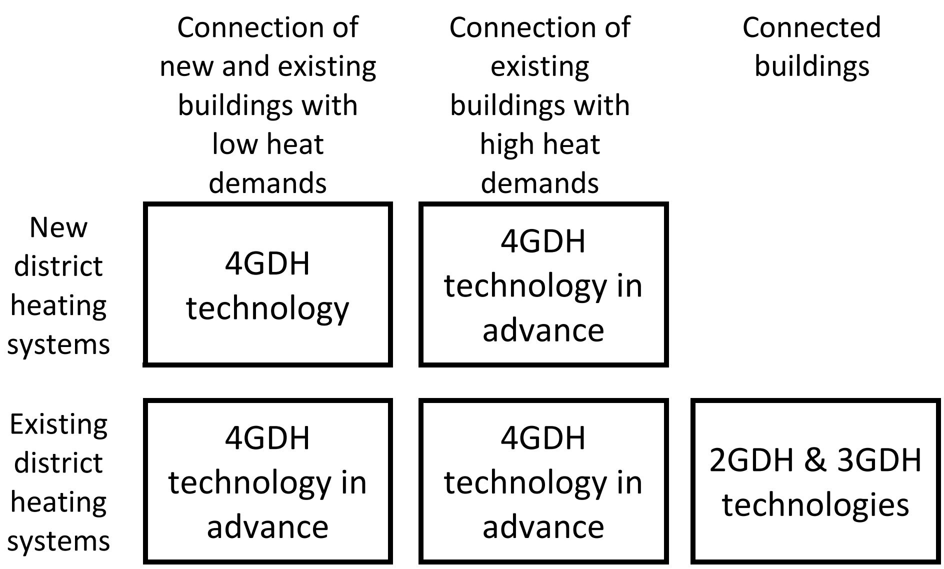


Figure 7. Overview of the five possible transformation strategies in order to obtain future district heating systems fully operating according to the 4GDH principles.

1.6 Project organisation

This project has been divided into three working phases:

Phase 1: Information collection of current temperature levels, experiences of reduced temperature levels, and temperatures used in customer heating systems.

Phase 2: Formulation of the proposed transformation roadmap by giving answers to the seven research issues put forward and writing the draft final project report.

Phase 3: Final report following expert feedback.

The project was performed in co-operation between the five national research teams from UK, Denmark, Germany, Sweden, and Switzerland. The Swedish research team coordinated the project. TU Dresden wrote section 1.4 and chapter 2, Halmstad

University wrote chapters 3 and 6 together with the remaining part of chapter 1, UNIGE and BRE shared the responsibility for chapter 4, and DTU wrote chapter 5. We shared the responsibility for the concluding chapters 7 and 8.

2 Previous generation shifts

The original source of district heating was steam generated in dedicated boiler houses and distributed from a central location to a large district. One of oldest systems was erected in New York City (U.S.) in the early 1880s. The steam has been used for distributed heating, cooking and power generation. The effort involved in the installation of a distribution network (including condensation pipes and all the safety devices) is more than balanced by the advantages of centralized generation. Specifically: heating and hot water without flames in the dwellings; large scale boilers operated at higher efficiency than individual ones; and heat has been available all the time.

Although heat losses from these first generation district heating (1GDH) networks have been limited by adding insulation to the piping systems, the efficiency of these high temperature systems is also limited. Nevertheless DH became a success story and there are now more than 800 DH systems in the US in the 21st century, mainly serving Colleges & Universities, healthcare installations and Community installations, respectively. The majority of these DH systems still use steam [Fiedler 2012].

Nevertheless over the years it became apparent that hot water as an alternative energy carrier to steam offers new opportunities to lower maintenance costs, to increase system efficiency and to use alternative fuels. Driven by DH performance optimization nowadays large number DH systems in cities all over the world are confronted with the transformation process from high to lower temperature operating conditions.

In the case of hot water systems operating at temperatures >100°C the lowering of temperatures would also reduce the required static pressure in the DH system. The shift of technology generations from 1GDH systems (steam) to 2GDH and 3GDH systems (hot water) may be driven by several reasons, e.g. reduction of heat losses, improving heat generation efficiency, introduction of waste heat and/or heat from renewable energy sources, reduced consumer demands, and economic aspects.

Some example experiences of previous shifts of technology generation of district heating are described in the following chapters.

2.1 Technology shifts from 1GDH

Steam was the predominant energy carrier for the early DH systems. Although mature technology is available to manage the transportation of steam and condensate, the advantages of steam including its high energy density, low auxiliary energy for transportation, and small size of building heat exchangers, are outweighed by its disadvantages.

DH network economy and heat losses, reduced building energy demand and space heating temperatures, and the integration of heat from waste and renewable into the DH system have led operators of 1st generation DH system to consider how to convert from steam to water based DH systems, thereby updating second or higher generations).

Consequently the operators of 1GDH networks had to choose among three options: to keep the steam distribution system, to convert to hot water distribution or to close down the steam distribution system. This section summarizes experiences with all three paths.

2.1.1 Keeping the steam distribution system

Example 1: New York, U.S.

The New York steam system began its operation in 1882. The company Consolidated Edison, Inc. (ConEdison) has operated the district energy system for over 130 years. It is nowadays the largest district steam system of its kind in the world. The Con Edison steam system is a substantial energy business with a customer base of over 1,700 customers (ConEdison 2013). Steam is not only used for different heating purposes and humidification but also to drive steam turbine chillers distributed all over the city. See Figure 8 for more detailed information about the location of A/C chillers.

Figure 8. Location of the Steam A/C customers (Jakob 2003)

About half of the steam supply comes from cogeneration units. Dedicated boilers generate the remaining steam capacity. Both CHP plants and boilers are fired by either natural gas or fuel oil. According to the Steam Long Range Plan (ConEdison 2012) there is currently no intention to switch from steam to another heat carrier such as hot or lower temperature water. This makes sense because the ConEdison steam system offers a reliable, flexible and simple steam supply with relevant benefits for the electric and gas sectors as well. It is also a financially stable business with reasonable return of investments.

In the future system improvement measures will be implemented: for example, remote monitoring to enhance safety, thermal efficiency improvement to reduce line losses, improve transport flexibility, study the behaviour of condensate in the system, and operational risk mitigation (ConEdison 2012). In addition, as a future option, customer-sited CHP will provide partial steam back-up to Con Edison's central cogeneration plant.

Recent trends in local cold-water generation and building site A/C system design together with electricity and fossil fuel prices have been identified as critical for the business.

2.1.2 Converting to hot water distribution

The transformation of an existing steam based DH system to hot water distribution can be realized again in three different ways: by adding dedicated hot water loops to the steam network (loop solution), by establishing and operating a separate hot water system in parallel for many years (changeover solution), or by switching from steam to hot water within a very limited period of time (makeover solution). There are examples and experiences available for all three possibilities:

2a) The loop solution: introducing separate secondary hot water loops connected to the steam system by heat exchangers, for enabling future conversion to a hot water system.

Example 2a1: Paris, France

The Paris DH system was initiated in 1927 when a first concession was been given to CPCU (Compagnie Parisienne de Chauffage Urbain; the Paris urban heating company). The delivery of DH began in 1930 by providing steam to Gare de Lyon. Nowadays one third of Parisians are served by the steam system where the steam is used primarily for heating but also for DHW and industrial processes, including laundry, cooking, sterilization, humidification and food processing.

The concession contract limits the maximum price for the heat delivered depending on the share of renewable heat generated (UNEP 2015). Some further facts and figures on the Paris system can be found in (UNEP_Paris 2015):

- Steam lines have diameters between 40 and 1100 mm (1.6 /43 inches)
- 5 774 sub-stations
- 8 million tons of steam delivered per year to 460 000 habitations
- 12 districts supplied

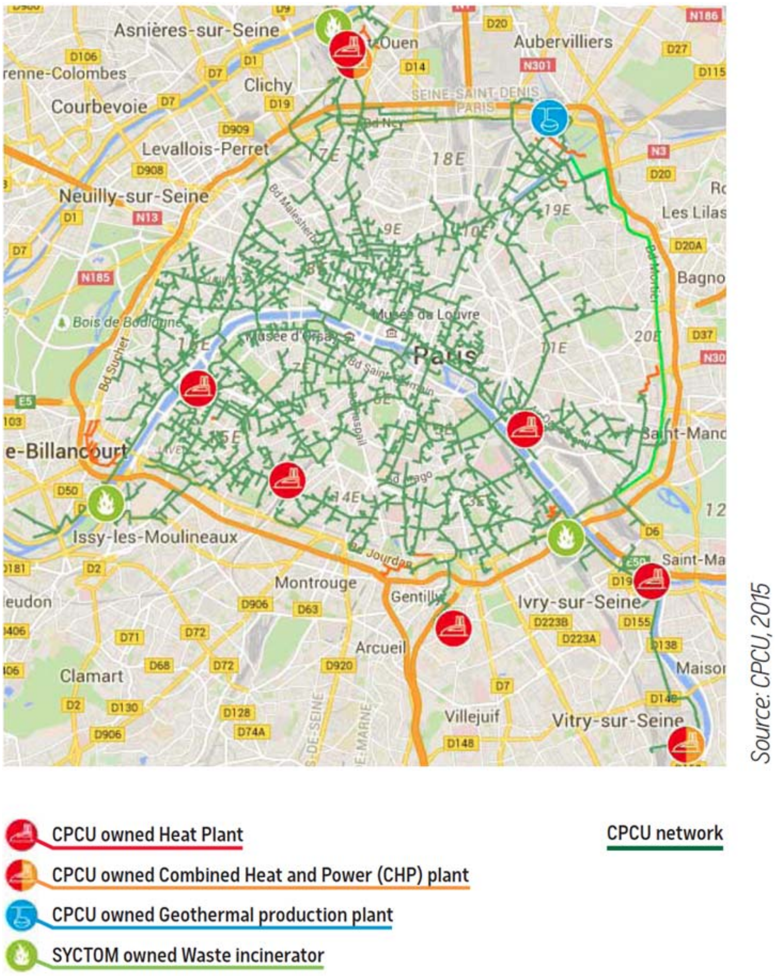


Figure 9. The DH network of CPCU showing heat production plants (UNEP_Paris 2015)

In 2013 5,5 TWh of heat were distributed through a 475 km network. Figure 9 shows the heat network. This network is still mostly based on steam but of course it has been recognized that the transport of hot water is more efficient. Besides the improved distribution efficiency the heat capacity effect of water is also used to reduce peaks in heat load profile. That is why a total of 19 hot water loops have been integrated to the steam network. In general when new areas are developed today, hot water loops are preferred.

Heat (resp. steam) is mainly generated by waste incineration. But following the Paris energy strategy it is planned to shift from fossil fuels to biomass, geothermal energy and biofuels (UNEP_Paris 2015). CPCU's target is to achieve 50 per cent renewable or recovered energy in heat production by 2015, and 60 per cent by 2020 [UNEP 2015]

2b) The changeover solution: starting a separate hot water system with its own heat supply such that this system will be the focus for long-term expansion, and culminating in the full replacement of the steam system in the future.

Example 2b1: Copenhagen, Denmark
The Copenhagen DH system was established in the 1920s. Originally a steam network was installed to supply heat to mainly industry and hospitals, but also other buildings including offices, institutions, and dwelling houses close to the steam pipelines were connected (COPH 2015a) and (COPH 2015b). Steam was taken from coal-fired CHP plants. Its temperature was about 300°C.

In 1930/31 a steam accumulator was added to the system. In 1934 a new CHP unit was taken into operation at the Gothersgade power plant. This was a backpressure plant supplying steam to the turbine at a pressure of 45 bars with a steam temperature of about 400°C. In summer the steam was not used for heating purposes but was utilized for additional power production at the power plant's low pressure turbine.

Over the years more boilers and CHP plants have been installed ending up in the late 1960s with steam pressure before the turbine of 115 bars and a temperature of 520°C. Steam from different sources was been fed into one common steam pipe. Nowadays the Greater Copenhagen area consists of four integrated DH systems with one third of the total heat demand in Copenhagen is still distributed as steam (see Figure 10).

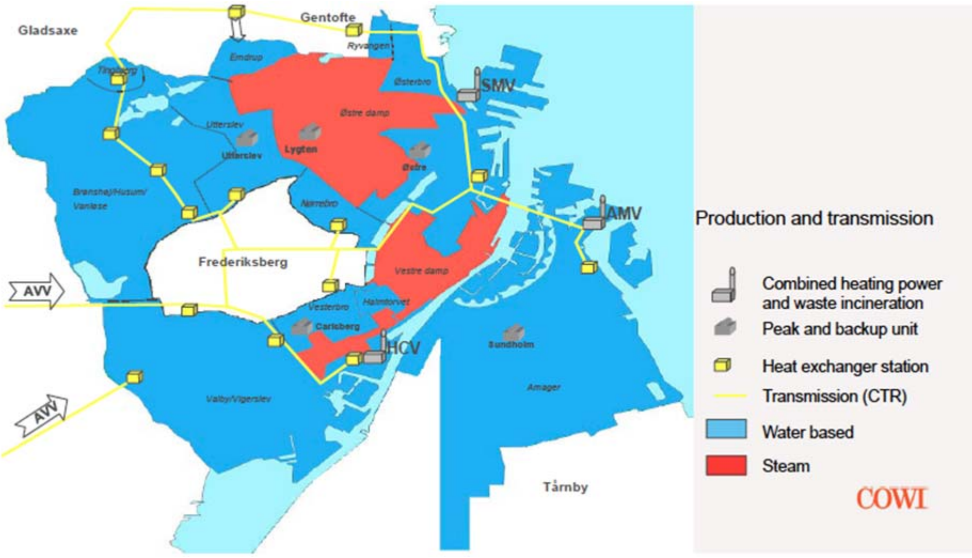


Figure 10. The DH system in the Copenhagen area (Hansen 2012)

The total length of the steam pipelines is about 160km thus representing one eighth of the total network. Aiming to lower the heat losses of the system, to increase economic benefit and to reduce CO_2-emissions the operator of the system (HOFOR; former Copenhagen Energy) is in the process of converting from steam to water. The conversion is planned to be completed by 2025. The conversion policy is in line with shifting from old and less efficient boilers and CHP plants to modern, i.e. more efficient heat generation plant based on waste energy and/or renewable energy sources (biomass). But as long as steam is used as the energy carrier in the DH system new CHP plants installed in Copenhagen (such as Amagerværket, AMV1) are obliged to supply steam. Communication with customers is part of the transformation process. Brochures have been published to explain the process (HOFOR 2013)

Example 2b2: Kiel, Germany

The steam DH system in Kiel was installed in 1905. Since the 1960s, hot water has begun to replace steam as the heating medium. Today more than 60,000 apartments, as well as many public buildings, including department stores, administrative and commercial buildings, and the university and hospitals are connected to the district heating network. The steam piping system has been in use up to 60 years and there is an aggressive program to switch to hot water piping.

Example 2b3: Ulm, Germany

The heat network providing heat to the university campus was originally operated with steam. As part of the redesign of the heat network this individual campus network has been connected to the central inner city DH system, switching it in the process from steam to hot water (AGFW 2013).

Example 2b4: Salzburg, Austria

The steam network of Salzburg city was established in the 1950s and operated with steam at about 200°C. In 2004 it was decided to transform it to a hot water district heating system that is now operated with temperatures varying seasonally between 95°C and 130°C depending on ambient temperature. Some of the existing steam pipe network could be used for hot water as well while other parts of the DH network had to be substituted with new pipes. Substations and control & metering devices have also had to be changed accordingly. Major experiences are (Laufkötter 2012):

- Documentation of the existing DH system to be transformed – mainly regarding the network scheme - is needed. In case it is not available some effort (costs and resources) has to be spent on surveys to get a clear picture about the current situation.

- A transformation strategy has to be set up. This strategy will help to ensure that client heat demands are still being fulfilled. Consequently, construction work could be done during the summer season only when no heat supply is needed. Consequently transformation will take a number of years depending on the size of the network. In the city of Salzburg it took about seven years from the very first decision about transformation until project finalization.

- Large customers do need dedicated and specific transformation measures. Communication and information about the transformation process helps to keep the customers on board.

- The opportunity for other related system improvements should be considered at the same time, e.g. integration of new heat sources (renewables, waste heat) and new installation technologies thus reducing maintenance efforts in the future.

Example 2b5: St. Paul, Minn., U.S.

It was in the late 1970s already when the existing legacy steam DH system was the subject of a feasibility study that was organized by the District Heating Development Corporation (DHDC) – the developer of District Energy St. Paul - and the Local Authorities. Based on the outcomes and recommendations of the study it was decided to replace the steam DH system with a European-style hot water system (where steam systems are sometimes called American style).

By 1983 the first DH customers began to receive heat from the hot water system. The DH generation was predominantly coal-fired in the 1980s and 1990s. In 1999 the construction of a biomass fueled CHP was been initiated resulting in St. Paul being North America's largest hot water DH system, currently serving about 80 per cent of the commercial, residential and industrial buildings in downtown Saint Paul and adjacent areas. (Spurr 2012)(St.Paul 2007)(St.Paul 2016).
Experiences that have been gained include:

- Federal, state and local government support is needed
- The hot water DH system is twice as efficient as the previous steam heating system in downtown Saint Paul, heating twice the floor area of building space with the same amount of fuel.

2c) The makeover solution: implementing the whole system transformation in a short period in order to switch as quickly as possible to a new hot water system, since the alternative hot water system is not available as in variant 2b.

Example 2c1: Munich, Germany
The local energy supply company in the city of Munich was operating Germany's largest urban steam system characterized by a pipe length of 250km, 4400 client substations and 1.2 GW generation capacity. Mainly driven by economic reasons but also taking account the energy efficiency indicators it was decided to switch from steam to hot water of 80°C to 140°C.

Based on a connection study the transformation process was started in 2003. The basic idea was to use former steam and condensate pipes for hot water transportation to avoid extensive and costly construction work. Nevertheless existing steel pipes will be substituted step by step with plastic jacket pipes when there are faults and malfunction.

In total a 10 year plan was set out to transform the existing steam DH network into a hot water system. Experiences of this transformation process are well described in (Stadtmüller 2004) and (Stadtmüller 2006). Following the description it was mainly the hydraulic performance of the DH system the engineers had to keep an eye on when shifting the system sector by sector. See Figure 11 where the original sectors of the DH system and the corresponding time schedule for shifting are highlighted.

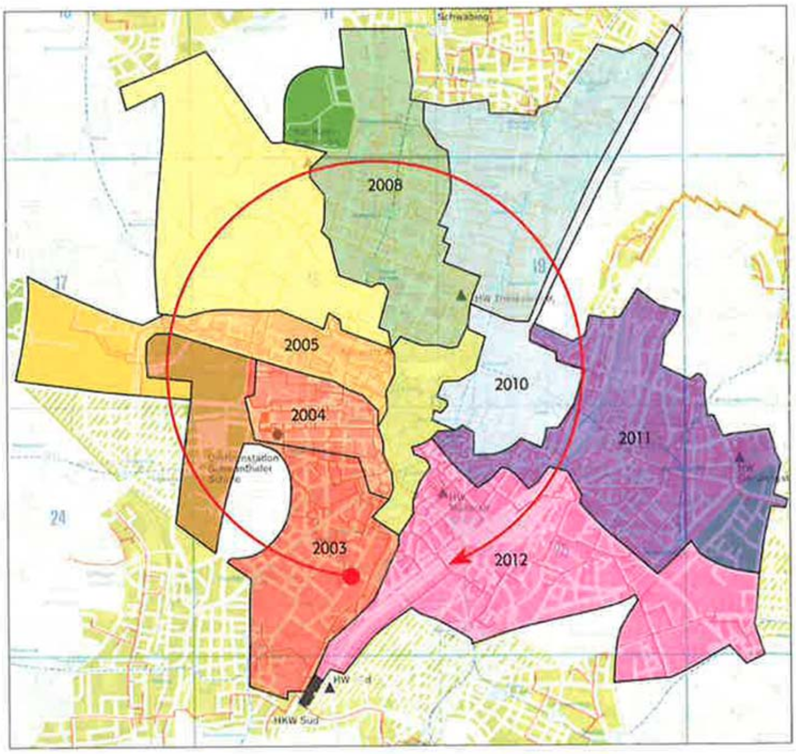


Figure 11. Sectors and time schedule for the transformation of the Munich steam system to hot water (Stadtmüller 2004)

As a consequence of shifting from steam to water all steam-water substations had to be substituted. This was carried out during summer time but customer heat supply was interrupted for maximum a week by optimizing the construction work flow. Clients requiring steam for industrial process have been either provided with dedicated steam generators or internal processes have been adjusted to match the hot water supply.

Condensate pipelines that have to be used again were pressurized to test for tightness at least a year before shifting from steam to water to be able to fix any damage due to higher system pressures.

Although the expected benefits from the transformation were in general achieved; however there were other problems to be solved:

- Strengthening of static performance is needed due to modifications in the system pressure.
- In case of sudden damage reparation of the old channel system was needed instead of installing new and modern piping systems to avoid time consuming planning and preparation phases.

Experiences gained during the transformation process in Munich have been used to start a pre-feasibility study for steam systems in Ulm, Dortmund and Würzburg, respectively.

Example 2c2: Vancouver, Canada

Steam is no longer the preferred energy carrier when the owners of DH systems are planning to convert from natural gas to renewable sources of energy (Vancouver 2015a). In line with the Neighborhood Energy Strategy approved in 2012 by Vancouver City Councils the conversion of the existing Downtown and Children's and Women's/Vancouver General Hospital campus steam heat systems from fossil fuels to renewable energy sources has been agreed on. The City takes leadership and provides support with a minimum of regulation when developing renewable energy systems.

The Renewable City Strategy (Vancouver 2015b) explains:

- "Downtown steam system:
  The privately owned downtown steam system serves more than 210 buildings and provides the single largest carbon emission reduction opportunity in the city. The City is working with the system owner to plan the conversion to renewable energy source. The conversion also has the potential to supply renewable energy to other neighborhoods in Downtown, including Northeast False Creek, South Downtown, West End, Downtown Eastside and False Creek Flats via new low-temperature hot water networks.
- Children's and Women's Hospital and Vancouver General Hospital campus steam systems:
  These systems are interconnected via an unused steam line. Reactivation of this steam line, and establishment of a new low carbon energy center at Children's and Women's Hospital provides a significant opportunity to increase renewable energy supply to the hospitals. The system also has the potential to expand to serve new developments and existing natural gas heated buildings in the Cambie Corridor and Central Broadway areas."

The conversion is part of the Greenest city 2020 action plan. Figure 12 presents an entire plan of Vancouver's Neighborhood Renewable Energy System

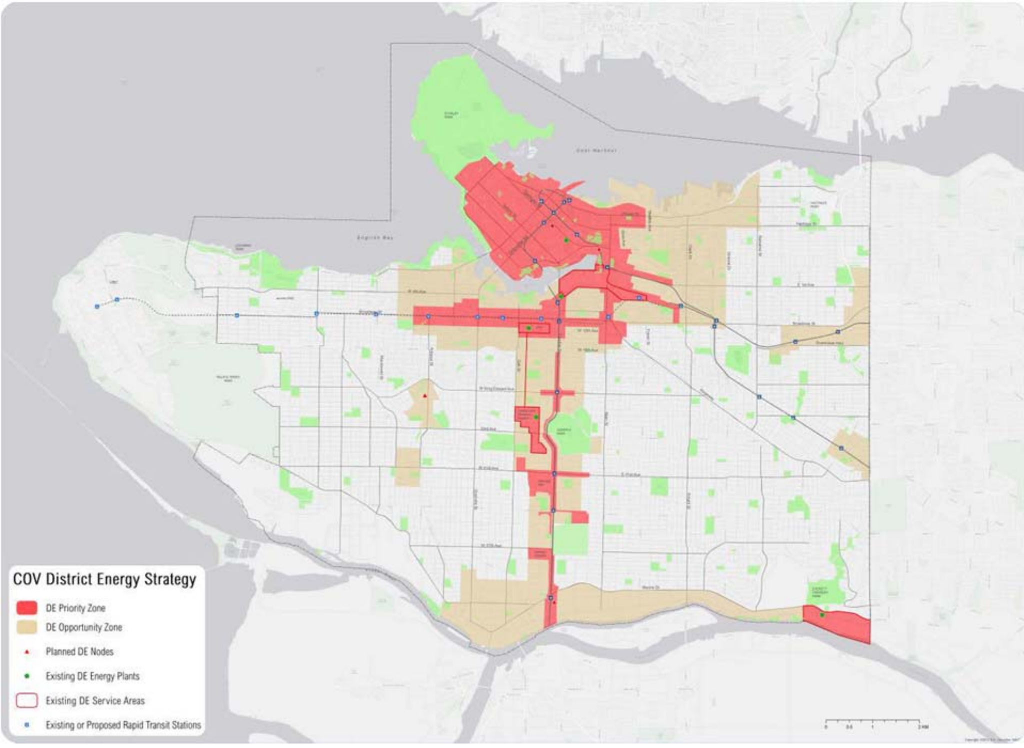


Figure 12. Vancouver's Neighborhood Renewable Energy System Service Areas (Vancouver 2015b)

Example 2c3: University of Rochester, U.S.

From [Pierce 2007] it is known that the DH system at the Rochester Campus was first established at the beginning of the 20th century. Steam was generated by coal-fired heating plant. Along with the expansion of the campus the steam network also had to be enlarged in 1924 and a second boiler plant was erected. The boilers were converted to natural gas in 1998. Steam was also used to provide chilled water generated by steam turbine-driven centrifugal chillers built in the 1970s.

Heat losses of the steam distribution network were estimated to be about 25% although the steam DH system was still in good condition. Incurring this level of heat loss while burning expensive natural gas rather than inexpensive coal led to the decision in 2004 to build a new hot water district heating system. Pre-insulated pipes with very low heat losses have been recognized as the preferred option for heat distribution.

The new hot water district heating system replacing the old steam distribution system came into operation in 2005. [Spurr 2012] states that construction costs of the hot water system were about $12.5 million in total; the distribution system itself counted for about 65% and building interconnection for about 35% of the costs. Steam pipes still under operation will be abandoned as soon as buildings still served by steam have been connected to the hot water loops.

2.1.3 Closing down the steam distribution system

For some reason it could happen, that existing steam DH systems closed down rather than replaced by a water based systems.

Example 3: City of Chicago, U.S.

The DH system was established in 1910, when the Illinois Maintenance Company introduced a different type of heat network. The idea here was to connect existing plants in order to close down the smaller and less efficient ones. The steam DH system was closed down by July 5, 1979 when the remaining 4 customers were disconnected. According to (Princeton 1982) the main reason was a lack of interest in DH due to this system's high losses and consequent high prices for steam compared to gas or electricity.

2.2 Technology shifts from 2GDH and 3GDH

The transformation or update from 2GDH to 3GDH and/or from 3GDH to 4GDH is 'just' requiring a further reduction of system temperatures. Once the temperature level has been reduced. several options can be used:

- integration of surplus heat, e.g. from industry and/or electricity production to the DH network,
- increasing share of renewable energy sources (e.g. geothermal and/or solar heat) in combination with the application of seasonal heat storage leading to no or minor use of fossil energies.

Further reduction of temperatures in the DH system could also be realized by:

- Direct connection of new 3GDH parts into the existing system. The supply temperature will be set for meeting the temperature demands in the 2GDH parts (the integrated solution). This is the simple solution since high 2GDH temperatures can always be used in medium 3GDH temperature areas.
- Adding new water loops (secondary networks) with their own lower temperature levels to the 2GDH system. The loops will be connected to the 2GDH system by heat exchangers (the loop solution, same as variant 2a for steam systems). Beside a complete shift from one DH generation to the next generation a combination or mix of different temperature levels can be realized. The

combination or parallel operation of high and low temperature water is normally done using ordinary substations; see Figure 13.

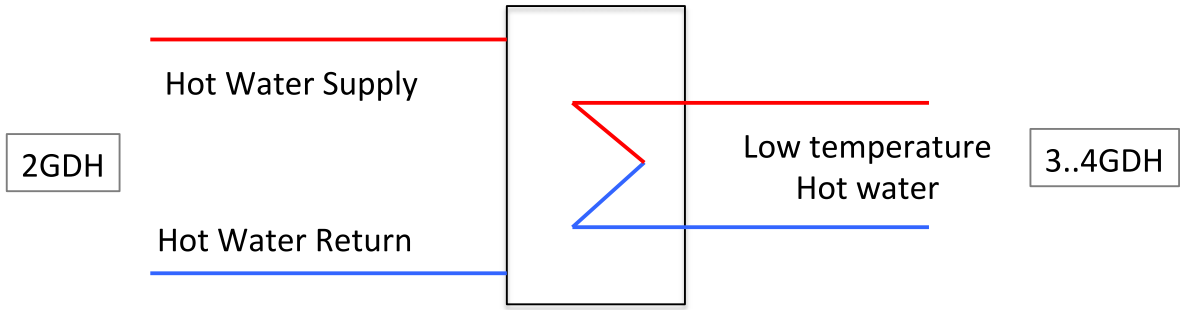


Figure 13. Connecting low temperature water loop to a high temperature water network (applicable to steam as well)

Adding a secondary loop to a DH primary network gives the opportunity to design the secondary DH loop for any temperature that is lower than the supply water temperature in the primary network thus combining different generations of district heating. From Figure 14 illustrating primary and secondary networks in the city of Dresden it can be seen that besides temperature reduction secondary networks can also be used to expand DHto new areas.

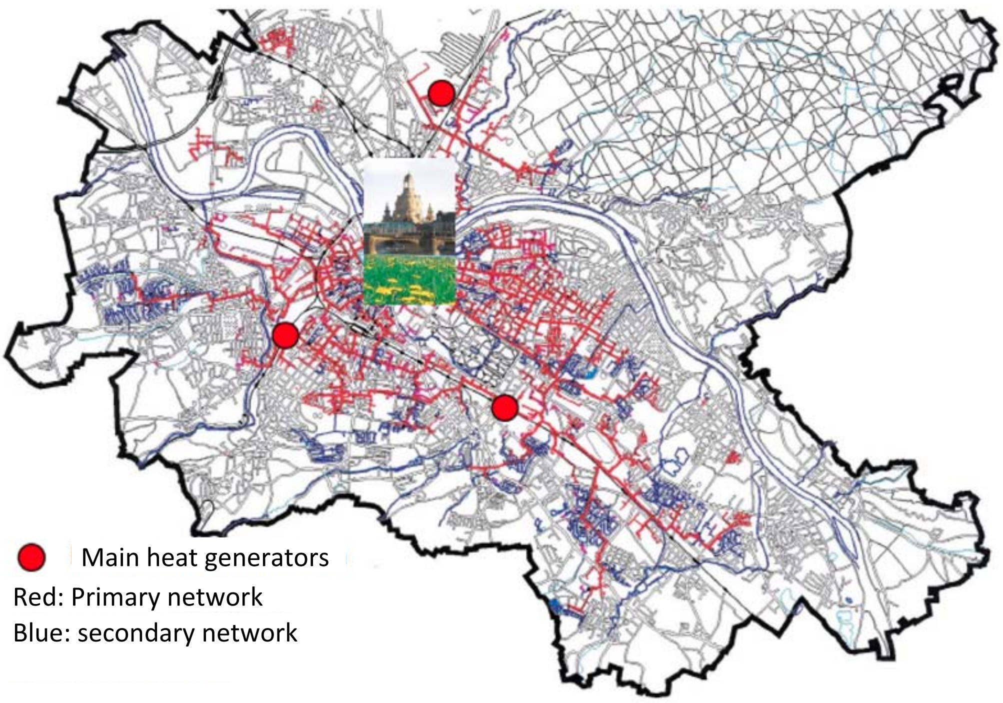


Figure 14. City of Dresden: Schematic of the DH network (DREWAG 2009)

- lowering the flow temperatures in both supply and return pipes whereas lower return temperatures will normally be a consequence of lowered supply temperatures. Nowadays the operators of DH networks are following this strategy taking into account energy saving measures having an impact on both peak and annual space heat demand of buildings connected to the DH system. In the case of single buildings in the district not yet prepared for lower supply temperatures heat pumps could be added to locally lift flow temperatures to meet those buildings' characteristics. As illustrated in Figure 15 local temperature elevation could be achieved for DHW only or for both DHW and space heating.

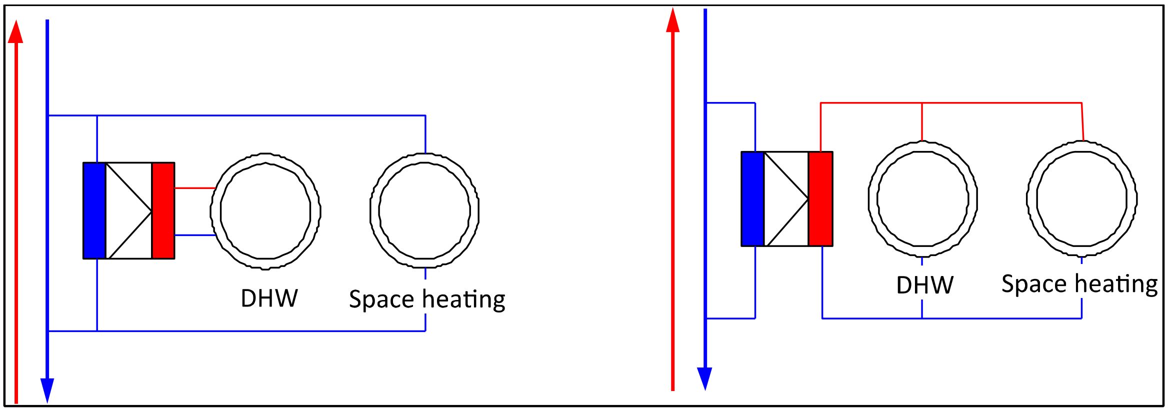


Figure 15. Increasing building energy system temperatures connected to low temperature DH [Felsmann 2010]

- lowering the return temperature only by adding a low temperature water loop to the existing DH system. Figure 16 shows how to connect the low temperature circuit to the return pipe. Supply water from the primary circuit is used to control the supply water temperature in the secondary circuit. This solution is for instance implemented in the Berlin DH system (Vattenfall, BTB)

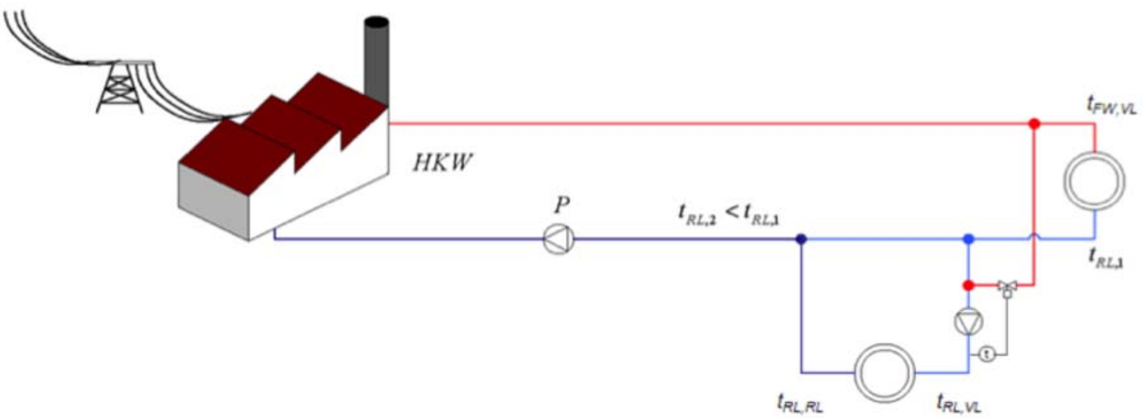


Figure 16. Principle of connecting a low temperature hot water loop to the return pipe [Felsmann 2010]

2.3 Conclusions from previous technology shifts

Technology shifting stands for any development along the DH generations from 1GDH to 4GDH. While it is quite easy to recognize the shift from 1GDH to any higher generation as this shift involves the substitution of steam by water as heat carrier, the shift among other DH generations is more difficult to decide on because of mixing different characteristics in the same DH system. That is also why technology shift is a precondition and the driving force for generation shift but it is not the same as generation shift. Technology is covering:

- Heat generation techniques and types of energy source (primary and secondary) used. In general there is a trend in heat generation technologies to move from fossil to renewable energy sources as well as using waste heat. Based on that DH reduces greenhouse gas emissions related to heat generation and offers the opportunity to provide heat from renewable energies to the customers. Both facts enable DH to contribute to local Sustainable Energy Action Plans or any strategic urban planning. In practice local authorities accounting for DH as a relevant component in the urban energy concept put pressure on the DH operator to rethink their heat generation policy. Otherwise DH would fall out of the list of qualified heat sources. Although heat from cogeneration is very relevant for today's DH systems, it will in future become less economically viable thus no longer presenting a robust business case and not competitive. Furthermore even waste heat from efficient cogeneration is based on fossil energy.
- Heat distribution systems connect heat generation sites to end users and customers. The heat distribution network incurs costs due to installation, maintenance, and operation. Operation costs are mainly due to heat losses along the pipes and the electric energy required for running the circulation pumps. So far, technology shifts are often motivated both by expected reduction of operational costs and improvement of energy efficiency of heat distribution systems. Energy efficiency and saving measures on the heat sink site allow the supply temperature in the DH network to be reduced. Low flow temperatures will lead to less heat losses thus increasing distribution efficiency. Multilevel DH systems combining (i.e. cascading) different flow temperature levels in one DH system can be seen as an option to shift from a lower to a higher GDH. Many DH systems have followed multi-level approach. DH systems using water as the heat carrier are easier and more efficient to install, maintain and operate than steam systems. That is why most 1GDH systems using steam are substituted by water based systems. As long as it is not possible to switch off the steam system and change

to a water system at the same time there will be a parallel operation of system parts using both steam and water. Finally, the original steam pipes will not be used any more but have to be removed.

Heat sinks have to be adapted to lower flow temperatures. That is why technology shifts at the generation and distribution site require energy saving measures (to reduce heat demand) or new heating technologies (e.g. instantaneous DHW water heaters resp. DHW storages; floor heating systems resp. radiators) on the customer side. Absorption chillers driven by high temperature DH have to be substituted by compression chillers.

From the aforementioned case studies presented in sections 2.1 and 2.2 it can be concluded that the transformation of existing steam systems to water based systems (using both hot and warm water) is motivated by a lot of advantages of water based systems, e.g.:

- Operation and maintenance costs of hot water systems are significantly lower than those of steam systems. There are cases in the US of steam DH being much more expensive than individual gas or oil boilersleading to such systems closing down (eg the former Chicago system)
- Reduced heat losses due to lower temperatures in the distribution networks in combination with increased efficiency of heat generation will reduce the demand of fuel and therefore also for primary energy
- The distribution of hot water is much easier to control than steam where the condensate has to be taken into account.
- Besides distribution both the higher heat capacity and density of hot water make it more attractive to store hot water than steam.
- Lower system temperatures facilitate the integration of waste heat and heat from renewable energy sources.

A full list of advantages/disadvantages of both water and steam systems is given in the evaluation report (Zhivov 2006). There one can find a summary of what should be taken into account when converting steam systems to hot water systems, e.g.:

- Both pipe distribution and heat exchange equipment at the customer interface and in the central heating plant need to be modified due to the fact that the heat capacity of hot water is lower than that of steam. It is highly recommended to verify any changes through thermal and hydraulic analysis.

- Whereas the steam supply pipe is often large enough for the distribution of hot water the returning condensate piping normally has to be replaced by a new return pipe to bring the hot water back to the power plant.
- New and efficient water-to-water substations to be installed in the buildings will lower the temperature spread in the water system compared with the bigger spread known from steam systems.
- Supply water temperature is easily controlled to compensate for heat demands varying with outside air temperature. Temperature control will have a positive impact on distribution heat losses and allows for an increase in the quantity of electricity produced by a back pressure steam turbine or by an extraction-condensing turbine.

Lower temperature levels in the hot water loop will enable the integration of other heat sources than just steam. With respect to that steam / hot water heat exchanger could operate as back up to other (renewable or waste heat) sources. Thus the hot water loop represents a DH system of the 2nd to 4th generation.

As well as provision of heating, a number of DH systems use steam and/or hot water to generate chilled water by integrating absorption chillers in their system. Normally absorption chillers are installed on-site providing chilled water at the building level rather than serving a separate district cooling (DC) network. While chilled water production with absorption chillers was a preferred solution years ago to equalize seasonal heat demand profiles, nowadays DH performance optimization (by lowering system temperatures) involves substituting absorption chillers with electrically driven compressor chillers.

3 Temperature levels in district heating systems

3.1 Temperature level definition

Network temperatures vary during a year, mainly with respect to the outdoor temperature. A Swedish example is provided in Figure 17. The supply temperature is kept at a base level during the low demand season (late spring, summer, and early autumn) in order to satisfy the customer temperature demand for providing DHW. During winter days with higher heat demands, supply temperatures are increased for two reasons: for satisfying higher customer temperature demands for space heating and for increasing the heat distribution capacity in the network.

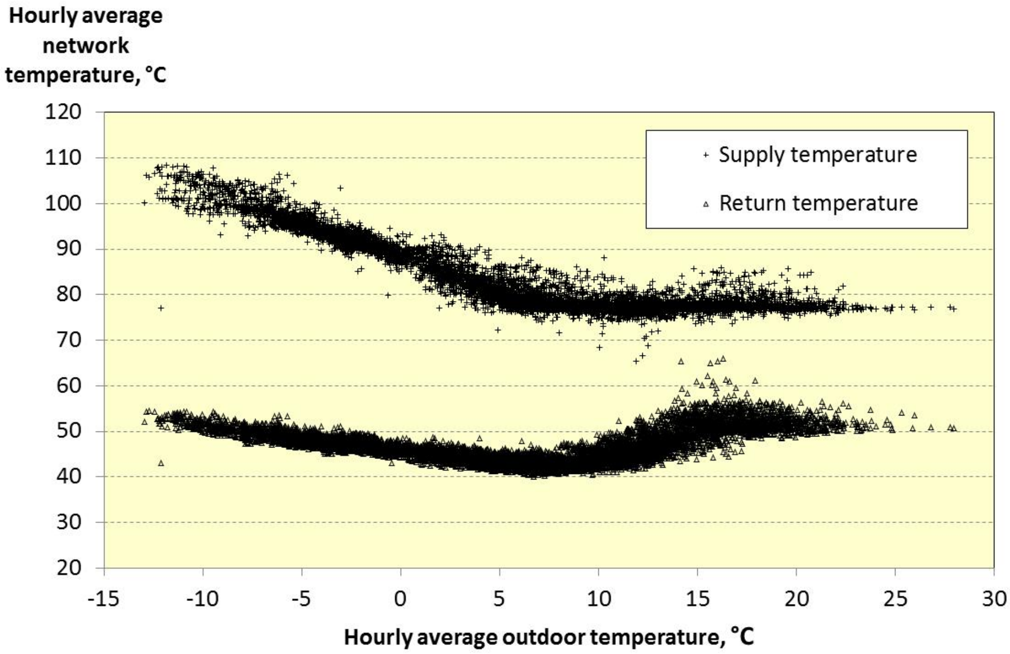


Figure 17. Consolidated hourly average network temperatures measured at the heat supply plants during 2010 in Helsingborg, Sweden. The annual average network temperatures were 84 and 47 °C, respectively.

The supply temperatures are cooled off in the customer substations and the circulating waters reach the return temperatures in each substation on the way back to the heat supply plants. Higher return temperatures when outdoor temperatures are low are the result of higher return temperatures in the customer heating systems. Higher return temperatures when outdoor temperatures are high arise from the bypass flows introduced for keeping the supply temperature high enough at the outskirts of the distribution network.

When analyzing and discussing temperature levels in district heating systems, it becomes difficult to cover all the seasonal variations of the network temperatures illustrated in Figure 17. Hence, for the analysis in this chapter temperature levels are defined by the annual arithmetical average supply and return temperatures.

These averages are not weighted with corresponding flows, as used when assessing the supply benefits of lower temperature levels. The arithmetical average temperatures are the driving forces for the heat distribution losses. However, the temperature difference between these two different average definitions is normally small.

3.2 Current temperature levels

This section contains a summary of European temperature level experiences mainly obtained in Sweden and Denmark, but some examples are also provided from Germany, Latvia, Poland, Switzerland, and Italy.

3.2.1 Temperature levels in 3GDH systems

A selection of temperature levels has been compiled for Swedish district heating systems in Figure 18 and for Danish District heating systems in Figure 19. It is noticeable from these figures that annual averages for both supply and return temperatures are higher in Swedish systems; this depends partly on a technical cultural difference. Specifically, in Sweden it is more common to have indirect space heating and closed hot water supply, i.e. heat exchangers between the distribution system and customer heating systems. Systems with high annual supply temperatures have either a major customer with high temperature demand, or bottlenecks, i.e. narrow pipes, requiring high supply temperatures to satisfy customer demand.

The theoretical achievable annual supply and return temperatures with current 3GDH substation technology are 69 and 34 °C for a typical error-free substation in Sweden. These temperatures are represented as the green bar leftmost in Figure 18 and were obtained from various simulations performed by (Gummerus 1989). Among the known data, all temperature intervals are higher than this theoretical potential. One Danish system is, however, close to the theoretical temperature level; in 2009 Marstal had annual supply and return temperatures of 74 and 36 °C respectively; their motive for efficient temperature level management is a large proportion of heat supply from solar thermal collectors.

Seeing that no system achieves theoretical temperature levels indicates systematic errors in the current third generation of district heating technology. Lower temperature levels are required in future technology design as competitive conditions will become more rigorous. Thus, it becomes increasingly important to address the deviation of actual from theoretical temperature levels.

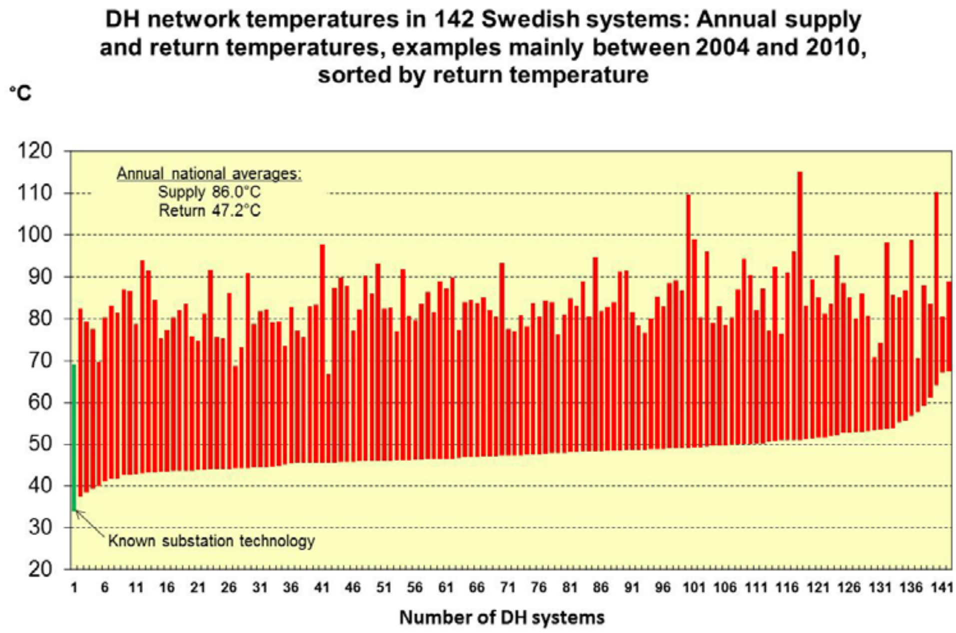


Figure 18. Typical temperature levels in Sweden. Source: (Petersson 2012)

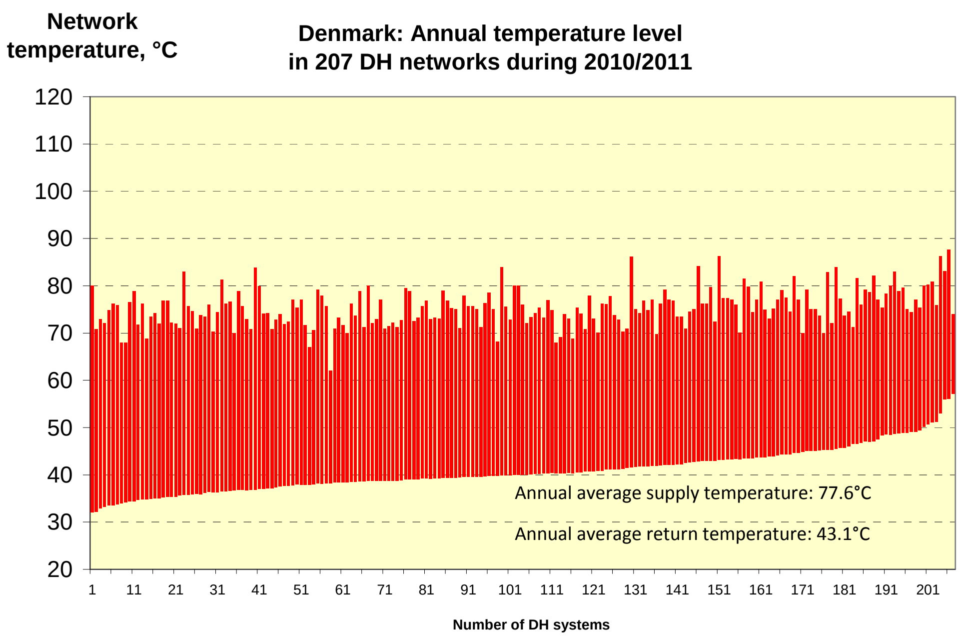


Figure 19. Typical temperature levels in Denmark. Source: (Dansk Fjernvarme 2011)

From a system perspective, errors occur at three distinguishable system locations: the distribution networks, customer heating systems, and customer substations. The first two areas mentioned are errors before and after substations. Substation errors may be divided into three different categories: design errors, malfunction errors, and set-point errors.

Errors in distribution networks arise from short-circuit flows, i.e. direct flow between supply and return pipe without any heat transfer in a heat exchanger. Short-circuit flows are necessary under certain circumstances, primarily during summer times when heat demands consist mainly of DHW preparation and network temperatures cool down due to low flows. A way round this error is to install thermostatic valves in the short-circuits. They will close when outdoor temperatures decrease, space heating demands increase, and sufficient flows in the network are achieved.

Errors in customer heating systems are more diverse and may consist of too small heat emitting surfaces in radiators, ventilation batteries and water heaters which results in a large flow and low cooling. Meanwhile, flows through water heaters may be unregulated resulting in a short-circuit flow. A complete lack of flow control through radiators or due to broken thermostatic valves results in erratic heat supply, and in the case of no heat demand a short circuit.

In heating systems which have been converted from using an oil boiler, removal of the three-way diverting valve whose purpose was to maintain a certain temperature in the combustion chamber and thus avoid condensation of sulphuric acid from fuel oil with high sulphur content may have been neglected, resulting in a short-circuit flow.

A frequently occurring error is lack of flow in hot water circulation systems; as the temperature decreases a temperature sensor will call for more heat from the control unit, which opens the valve on the primary side resulting in a short circuit. The solution to this error is to make sure that the temperature sensor on the hot water circulation system is located close to or in the heat exchanger.

Errors in substations can be divided into a matrix of locations and categories. First, design errors consist of errors related to the design phase for heat exchangers, control chains, and system design. Second, malfunction errors refer to well-designed components, but they have in some way lost their function after installation; these errors occur in heat exchangers and control chains. Third, set-point errors appear only in control chains.

- Design errors in heat exchangers relate to older heat exchangers which predate the automated soldering in current flat heat exchangers; it was primarily tube heat exchangers in which manufacturing errors occurred. Further sources of errors include the wrong size of heat exchangers being installed, resulting in suboptimal operation, and heat exchangers installed in parallel flow instead of counter flow operation.

- Design errors related to control chains consist mainly of misplaced temperature sensors, incorrectly installed control units, misplaced actuators with regard to fast and slow regulation for DHW and SH, but also with regard to rated pressure levels and choice of control valve.

- Design errors related to system design consist of the application of the wrong assembly principle for hot water circulation and inaccurate operation of valves which operate towards the same set-point.

  All these three design errors in substations are examples of proper substation standards and recommendations being ignored at the design phase.

- Malfunction errors related to heat exchangers consist of fouled heat exchangers and difficulties to replicate flow resistance in two parallel heat exchangers. However, fouled heat exchangers are an exaggerated problem, since actual occurrences are infrequent.

- Malfunction errors related to control chains arise from brokenf temperature sensors, damaged control units, broken actuators, and stuck valves.

- Set-point errors related to control chains appear when the temperature set-point value in the control unit is close to or higher than the primary supply temperature; also when the three-way valve set-point is lower than the set-point for the primary control valve. Then valves may oscillate without reaching a balance. According to (Frederiksen 2013), these kinds of temperature errors are the most frequent ones.

Supply and return temperatures in Figure 20 and Figure 21 correspond to the temperatures from Figure 18 and Figure 19, but are now plotted against the annual amounts of heat sold or heat supplied. The conclusions from these two diagrams are that temperature levels are not dependent on system sizes. High return temperatures occur in both small and large systems.

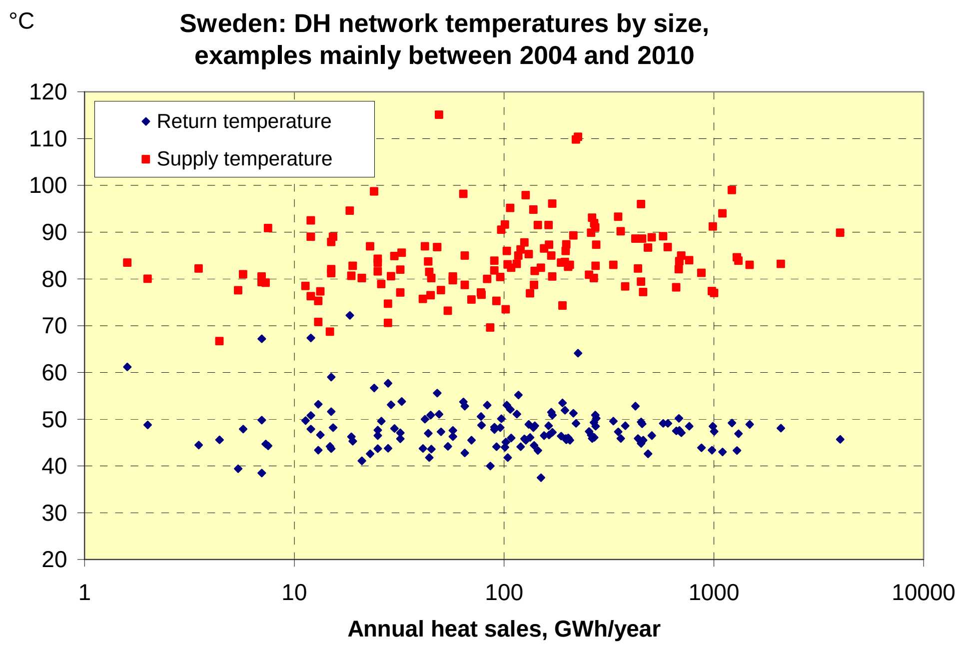


Figure 20. Network temperatures in Sweden correlated to annual heat sales and the network temperatures from Figure 18.

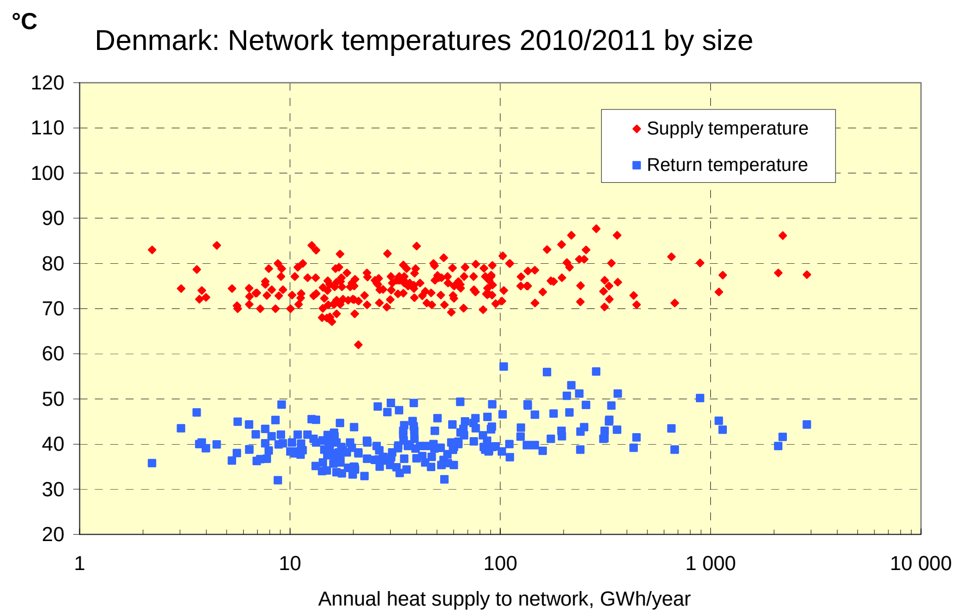


Figure 21. Network temperatures in Denmark correlated to annual heat supply and the network temperatures from Figure 19.

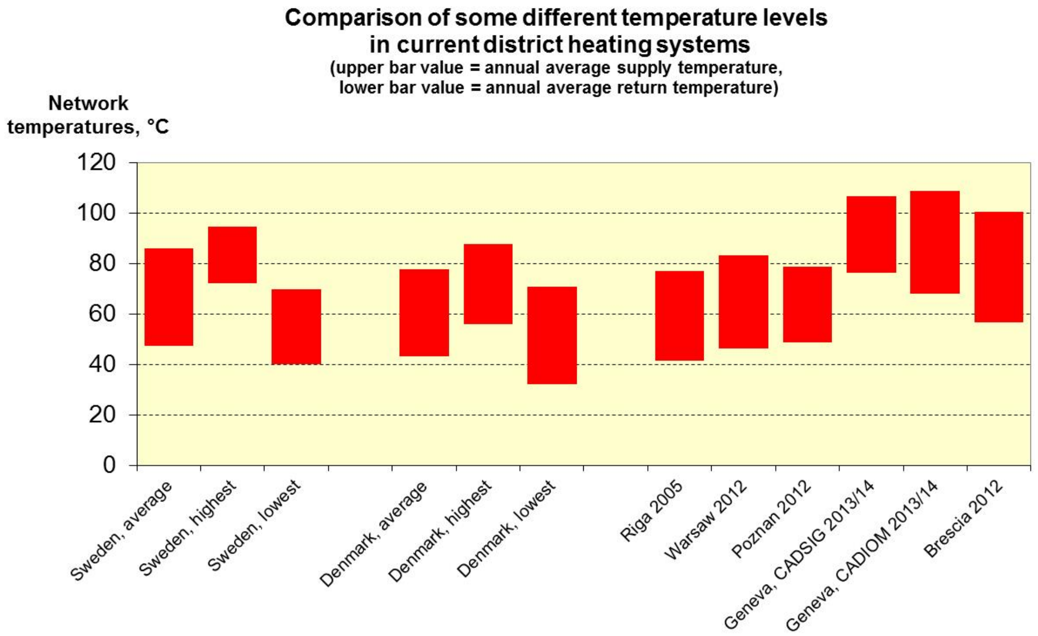


Figure 22. Typical annual average supply and return temperatures in heat distribution networks for various current systems.

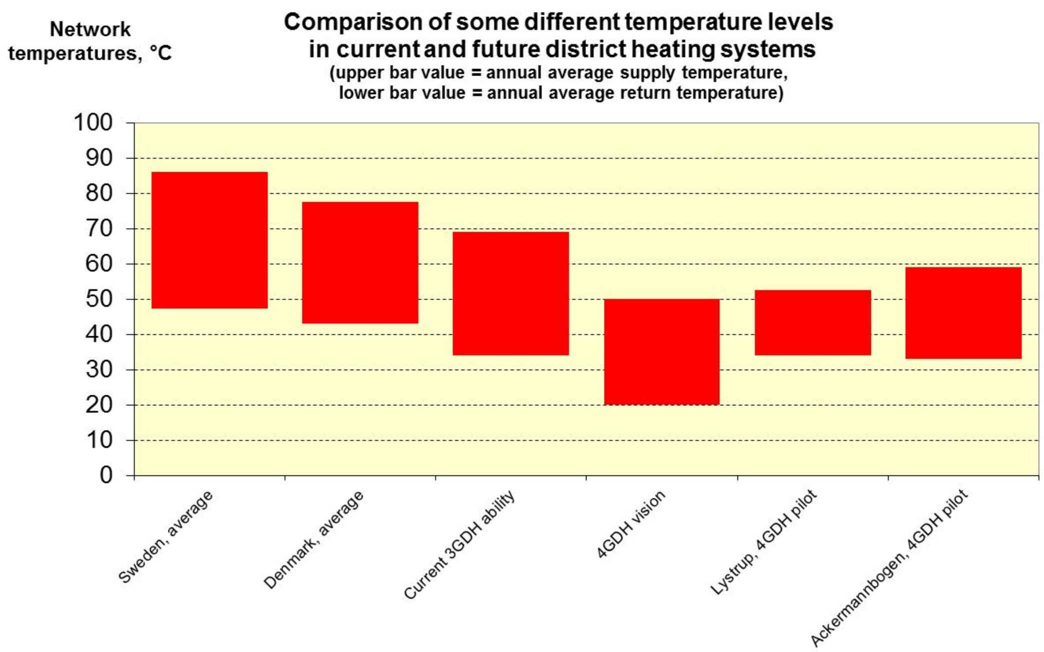


Figure 23. Typical annual average supply and return temperatures in heat distribution networks for both current and various 4GDH systems.

The average and extreme network temperatures in Sweden and Denmark are compared to six other European district heating systems in Figure 22. This figure shows that the temperature levels in Riga, Warsaw, and Poznan are similar to the Swedish and Danish systems. These three systems can all be regarded as 3GDH systems with respect to their temperature levels. The temperature levels in the two Geneva systems and in the Brescia system are considerable higher with annual average supply temperatures close to or above 100 °C. The return temperatures are also rather high. These three latter systems can all be regarded as 2GDH systems with respect to their temperature levels.

The average temperature levels in Sweden and Denmark are compared in Figure 23 with the expected theoretical temperature level for 3GDH and 4GDH systems together with two 4GDH pilot areas documented in (Dalla Rosa et al 2014). The temperature errors are more pronounced in Sweden than Denmark when comparing both with the expected 3GDH temperature levels. For both countries removing existing temperature errors should belong to their long term strategies for reaching future 4GDH standards. The explanation for the difference in network temperatures in Sweden and Denmark is again the exclusive use of indirect connections with heat exchangers in Swedish substations. Many networks in Denmark apply direct connections without heat exchangers, giving no extra addition to the temperature level from heat transfer in heat exchangers. The figure also shows that the two early 4GDH pilot systems have not been able to provide the expected return temperatures in 4GDH systems. Hence, future 4GDH pilot systems must address the issue of how to reach really low return temperatures.

3.2.2 Temperature level as driver for distribution heat loss

Lower temperature levels will provide lower heat losses from heat distribution networks. According to (Frederiksen et al 2013), the annual distribution heat loss is proportional to the annual degree-time number for heat distribution, being the time integral for the temperature difference between the network temperatures and the ambient temperature. Degree-time numbers are presented in Figure 24 and Figure 25 for the same average network temperatures provided in Figure 22 and Figure 23. The average annual degree-time number for the five 3GDH examples (Sweden, Denmark, Riga, Warsaw, and Poznan) in Figure 24 is 463 000 °Ch. The corresponding number for the three 2GDH systems is 667 000 °Ch, revealing that the average distribution heat loss in these systems is 44 per cent higher than for the 3GDH systems, with respect only to the temperature level.

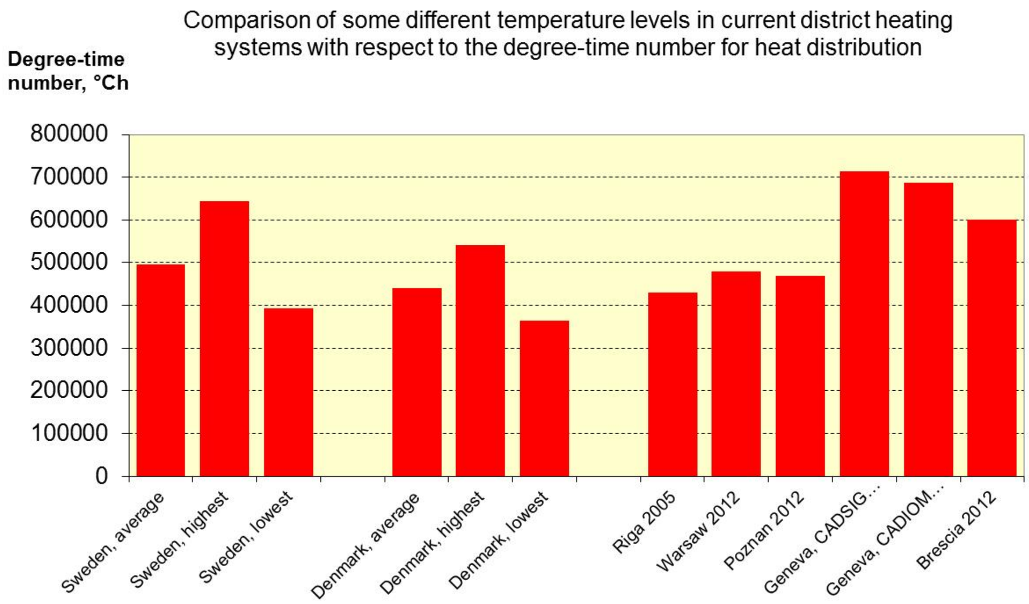


Figure 24. Degree-time numbers for heat distribution for various current systems.

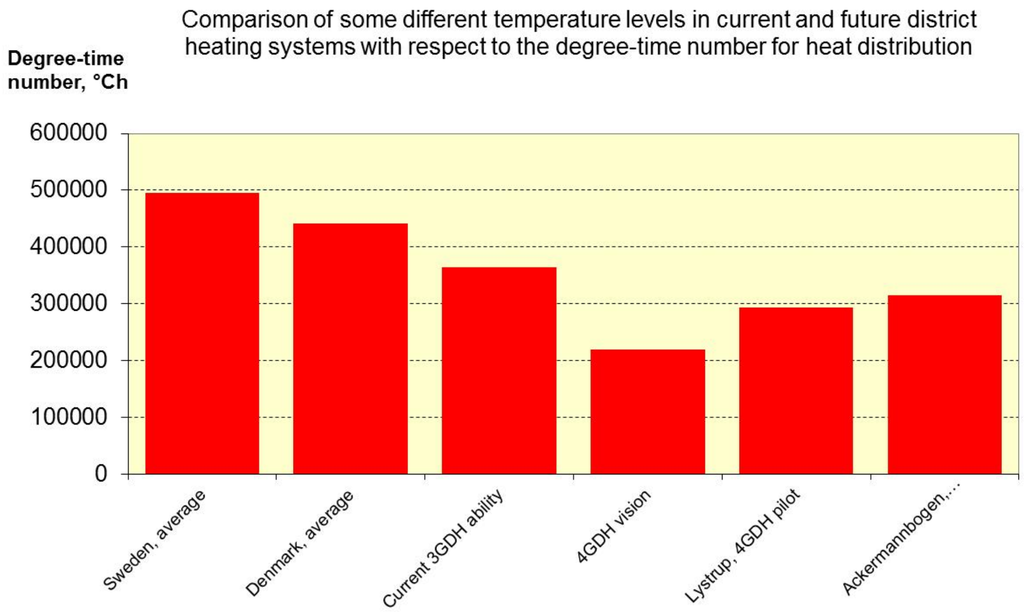


Figure 25. Degree-time numbers for heat distribution for both current and various 4GDH systems.

The degree-time number for the 4GDH vision is about 220 000 °Ch, revealing that the average degree-time number is about three times higher for the current 2GDH systems and just above two times higher than for the current 3GDH systems. The transformation from current 3GDH systems to future 4GDH systems can be divided into two steps according to Figure 25. The first step is to eliminate all current temperature errors corresponding to 40 per cent of the required change, and the remaining 60 per cent of the change should be organized in the second step by applying lower temperature demands in customer heating systems. Figure 25 also reveals that the degree-time numbers for the two early 4GDH areas of Lystrup and Ackermannbogen are, respectively, 34 and 44 per cent higher than the degree-time number tor the 4GDH vision. Hence, lower heat losses should be obtained in new areas aspiring to the 4GDH vision.

The future customer demand level is also very important for the relative annual distribution heat loss. This can be exemplified by comparing the current situation in a distribution area with high specific demands with a future situation with considerably lower specific demands, while keeping the same temperature level in the distribution area. The typical current situation in Nordic countries consists of specific customer heat demands of about 160 kWh/m^2.yr and annual distribution heat losses of 10 per cent. Then the heat losses corresponds to 18 kWh/m^2.yr. In the future situation, the customer specific heat demands are reduced to 40 kWh/m^2.yr. Then the annual distribution heat loss will become 31 per cent, giving a much more difficult business case for district heating. In order to keep the same heat loss percentage as in the current situation, the future distribution heat loss should correspond to 4.5 kWh/m^2.yr. This can be accomplished by a combination of reduced temperature levels and increased heat resistances in the insulated distribution pipes.

3.2.3 Thermal lengths in district heating substations

Heat exchangers are often used in substations in order to transfer heat indirectly to customer radiator and ventilation systems, and for preparing DHW (closed hot water supply). The ability to transfer heat in a heat exchanger depends on its thermal length (also known as the Number of Thermal Units, NTU). The longer the thermal length, the easier it is to keep a small temperature difference between the warm sides (district heating) and the cold sides (space heating and hot water preparation) in the heat exchangers. When heat exchangers are used, these temperature differences increase always the temperature levels somewhat in the distribution networks, especially the supply temperatures.

Hence, a longer thermal length in heat exchangers is one important tool for obtaining lower supply temperatures in heat distribution networks at constant customer temperature demands. This is especially important for the heat exchanger for hot water preparation when setting the demand for the network supply temperatures for many days with low heat demands (late spring, summer, and early autumn).

The development of thermal length recommendations for substation heat exchangers during the last fifty years in Swedish is illustrated in Figure 26. The figure reveals that thermal lengths have become longer over the years. This has been accomplished by using some of the productivity gains from more efficient heat exchangers to buy heat exchangers with longer thermal lengths. This long-term development with more efficient heat exchangers in use will probably continue, so we will see considerably longer thermal lengths in future substations.

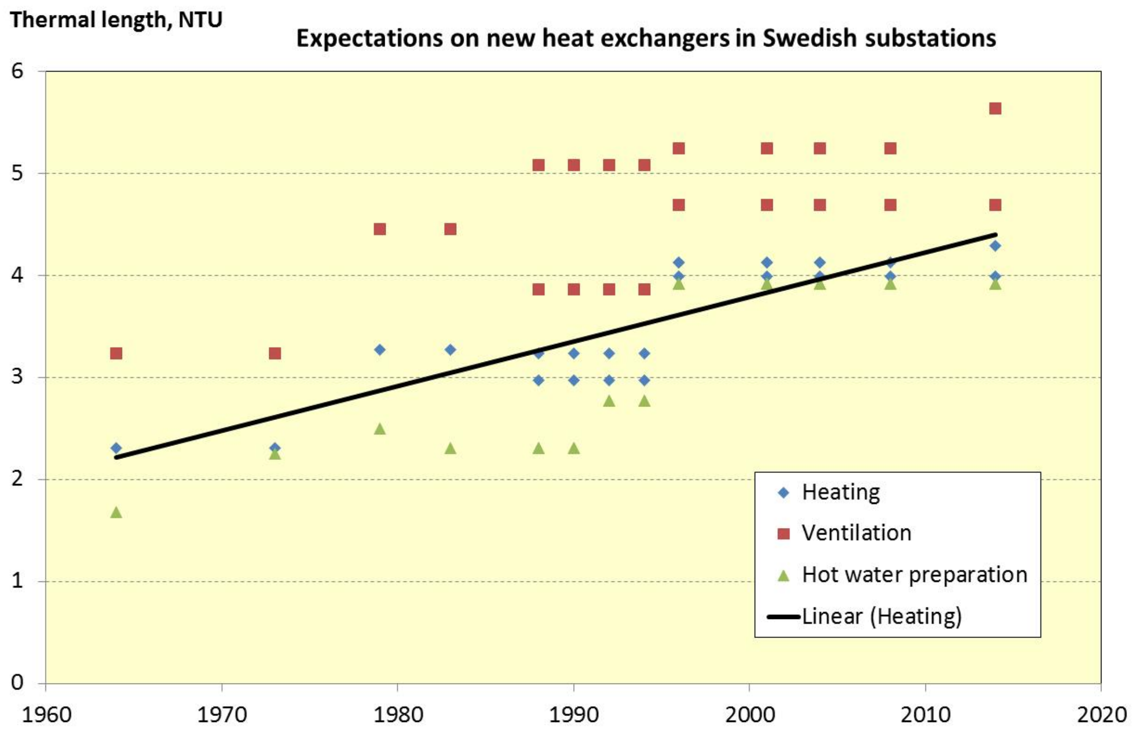


Figure 26. Examples of thermal lengths required in various published design recommendations for district heating substations in Sweden.

The heat exchangers for hot water preparation in the 4GDH pilot system of Lystrup were designed for the temperature regime of 50-20/14-47 °C according to (Dalla Rosa et al 2014). This temperature program corresponds to a thermal length of 7.6. This means that longer thermal lengths have already been implemented in 4GDH pilot systems. Hence, we should consider using heat exchangers with thermal lengths within the range of 6-8 in future 4GDH systems.

3.3 Reduction of current temperature levels

The possibilities for getting lower temperature levels in future heat distribution networks are summarized below based on the explanations for current medium temperature levels, the measures to be implemented in order to reduce the temperature levels, and the resulting system benefits from the reduction of temperature levels.

3.3.1 Explanations for current temperature levels

According to the previous section, the four major explanations for the current medium temperature levels in 3GDH systems are:

- High customer temperature demand levels originating from high specific heat demands and some heat use in high temperature applications (such as local absorption chillers).
- Errors in customer heating systems creating high return temperatures for the substations.
- Errors in customer substations creating high return temperatures for the distribution networks, including short thermal lengths in substation heat exchangers.
- Errors in distribution networks: short-circuit or by-pass flows have been implemented between supply and return pipes in order to compensate for high supply temperature drops in sparse distribution areas, due to relatively high heat losses at low heat demands, notably during summer nights. This leads to return temperatures being unintentionally raised due to mixing with higher supply temperatures.

However, these explanations are not new. They have been recognized for many years, as in (Woods et al 1999) and (Zinko et al 2005), both published within the IEA-DHC research program.

3.3.2 Measures to be implemented

A long-term strategy for lower temperature levels in existing heat distribution networks should contain the following measures to be implemented:

- Customer buildings: Implementation of energy efficiency measures in order to reduce high customer heat demands and avoid using high temperature applications.
- Substations and customer heating systems: Continuous commissioning by ICT systems for reducing temperature error times by early identification and monitoring of corresponding frequencies.
- Substations: Modification of flow control systems in substations by ignoring temperature set-points close to or above the current supply temperature to the substation.
- Substations: Use of heat exchangers with thermal lengths of 6-8.
- Distribution networks: Introduction of three pipe system with two supply pipes and one return pipe. The supply water will be circulated in the two supply pipes during times with low heat demands in order to maintain the required supply temperature. This measure will eliminate the current use of short-circuit or by-pass flows between supply and return pipes in distribution networks. Hereby, low return temperatures will not be polluted and mixed with higher supply temperatures.

3.3.3 System benefits obtained

When the proposed measures above are implemented, the following system benefits will be obtained:

- Lower customer temperature demands, from lower specific heat demands and by retaining the current radiator sizes.
- Lower return temperatures from elimination of errors in customer heating systems and customer substations, and from no short-circuit or by-pass flows between supply and return pipes in distribution networks.
- Lower supply temperatures from lower return temperatures and from lower temperature drops in the supply flow.
- Lower distribution heat losses, since lower temperature levels will be obtained from lower supply and return temperatures.
- Higher possibilities for utilization of low temperature heat resources, either by heat recovery or direct use of natural resources.

3.4 Conclusions about current temperature levels

With respect to current temperature levels in DH systems, the following main conclusion can be drawn: current temperature levels are elevated compared to expected temperature levels because of temperature errors in distribution networks, customer substations, and customer heating systems.

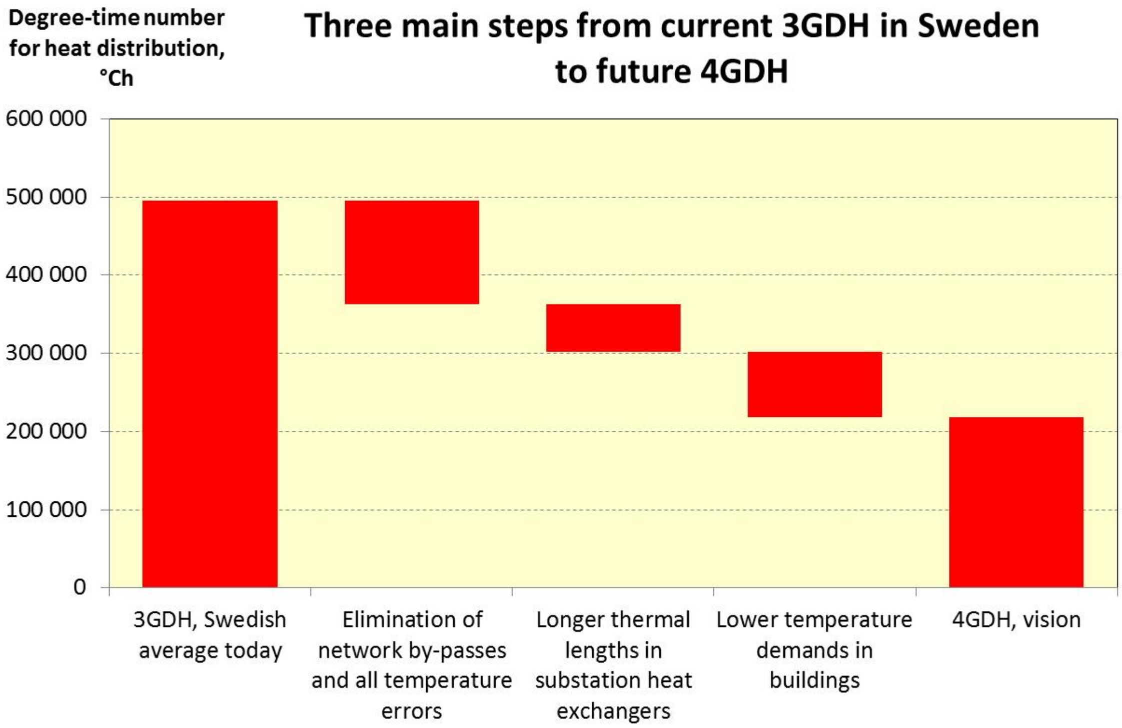


Figure 27. Estimation of the three main steps for obtaining lower temperature levels in Sweden.

With respect to possible reductions of temperature levels in future 4GDH systems, three main strategies can be identified from this analysis of current temperature levels. The magnitudes of these three reduction strategies are estimated in Figure 27 for Sweden. The three steps are:

1. Elimination of all identified temperature errors in distribution networks, customer substations, and customer heating systems in current 3GDH systems (about half of the total required change from current 3GDH to future 4GDH systems in Sweden)

2. Longer thermal lengths of substation heat exchangers (about one fifth of the required change)

3. Reduced temperature demands in both new and existing buildings from low specific heat demands and more radiator surfaces in existing buildings with small reductions of specific heat demands (about one third of the required change).

The possibilities of implementing these three main strategies will be further examined in the following two chapters.

4 Temperature levels in customer heating systems

In order to address this part of the work two approaches were taken.

The first draws on detailed research that has been carried out in Switzerland on temperature levels in customer heating systems. The results of this work form the bulk of the material in this chapter with a detailed study about current temperature levels (see section 4.1) and possibilities for reduction (see section 4.2). Each section is separated into two parts, Space Heating (SH) and Domestic Hot Water (DHW). In section 4.1.3, the importance of management is discussed.

The analysis in this first part of the work in this chapter is the result of focused research. This has involved the dedicated collection of detailed information relating to the customer heating systems. However, this extends only to those systems that fell within the study, and is confined to just one country (Switzerland).

Consequently, the project team also decided (section 4.3) to investigate more widely whether any further useful information could be obtained. A survey (Appendix A) was devised and distributed among district heating practitioners internationally. It became apparent from the survey outcome, however, that temperatures in customer heating systems on DH systems are not routinely monitored.

4.1 Current temperature levels

Extensive work has been carried out in Switzerland to determine actual temperatures used for SH and DHW. These are presented in the following two sections. Some further information, arising from the survey is provided in section 4.3.

4.1.1 Space heating (SH)

Generally, the supply temperature for SH is regulated according to the outdoor temperature during the heating season.

When heat is delivered with radiators, the expected supply temperature at the design (outdoor) temperature can be quite high (up to 70°C in Switzerland, or more than 82°C in UK) especially in old buildings (before 1990s).

In recent buildings (after 1990s), the supply temperature is generally between 40 and 50°C. In new buildings equipped with underfloor heating systems, the supply temperature is typically between 25 and 35°C. In older floor heating systems, the supply temperature can reach 50-60°C.

For most district heating systems space heating accounts for the majority (typically 60% to 80%) of the demand. Only with systems that are serving new build highly energy efficient buildings does the DHW demand exceed the space heating demand.

In Switzerland, regulation demands good practice. Specifically, through the Swiss standard for SH (SIA 2009), new heat emission systems for radiators and air heaters must be designed and operated so that the supply temperature does not exceed 50°C at the design outdoor temperature (the target value is 40°C). Specific values are provided for floor heating: a maximum of 35°C and a target value of 30°C. Each country has a different standard. Table 1 shows the maximum design supply and return temperature from different countries and different new heat emitters:

Table 2. maximum supply and return temperature for new heat emitters at design outdoor temperature according to different countries standards

Country	Standard number	Heat emitters	Maximum design supply Temp	Design return Temp
Switzerland	SIA 384/1	New radiators	50°C	
Switzerland	SIA 384/1	Floor heating	35°C	
Denmark	BS3528	Old radiators	90°C	70°C
Denmark	DS469	New radiators	70°C	40°C
Germany	EnEV 2014	New radiators	55°C	
UK		Old radiators	82°C	71°C
Sweden	No standard	-	-	-

The temperature levels for SH mentioned in this section are all observed values in existing buildings. Most of the data are taken from a measuring campaign carried out by the University of Geneva on a sample of 62 buildings in Geneva, Switzerland (Quiquerez et al. 2013).

Supply temperatures were measured for about 120 distribution loops during short periods in winter (generally two weeks during winter 2012) with a high time resolution (5 minutes). Figure 28 shows the location of the temperature sensors. Where possible, return temperatures were also measured. Most of the 50 studied buildings are residential buildings. Other building characteristics (type of emitters, building age, thermal demand etc) are also known.

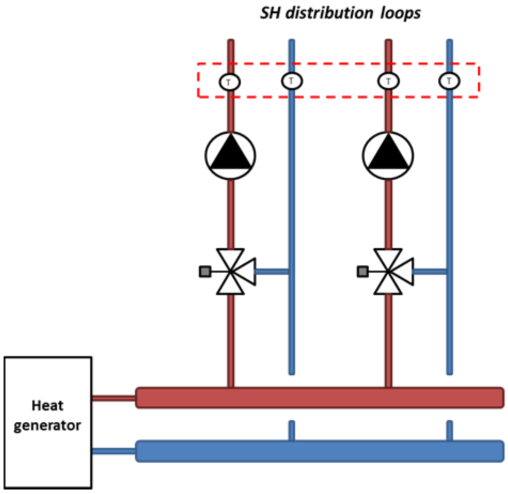


Figure 28. Location of the temperature sensors in the heating distribution loops (circled in red).

As expected, the measured supply temperatures are dependent on the outdoor temperature and the type of emitter (see Figure 29). The supply temperature when ambient temperature is -5°C (design temperature in Geneva) is higher in case of radiators (55-60°C) than in case of floor heating (33-44°C). The median supply temperature drops linearly from 62°C for an outdoor temperature of -10°C to 36°C for an outdoor temperature of 15°C in the case of radiators (respectively 40 to 28°C in the case of underfloor heating).

It has to be noted that the type of emitter in Europe is mainly radiators. In Sweden, a study from Boverket (2010) showed that the share of radiators was 70% in individual housing, 76% in tertiary buildings and 95% in collective housing.

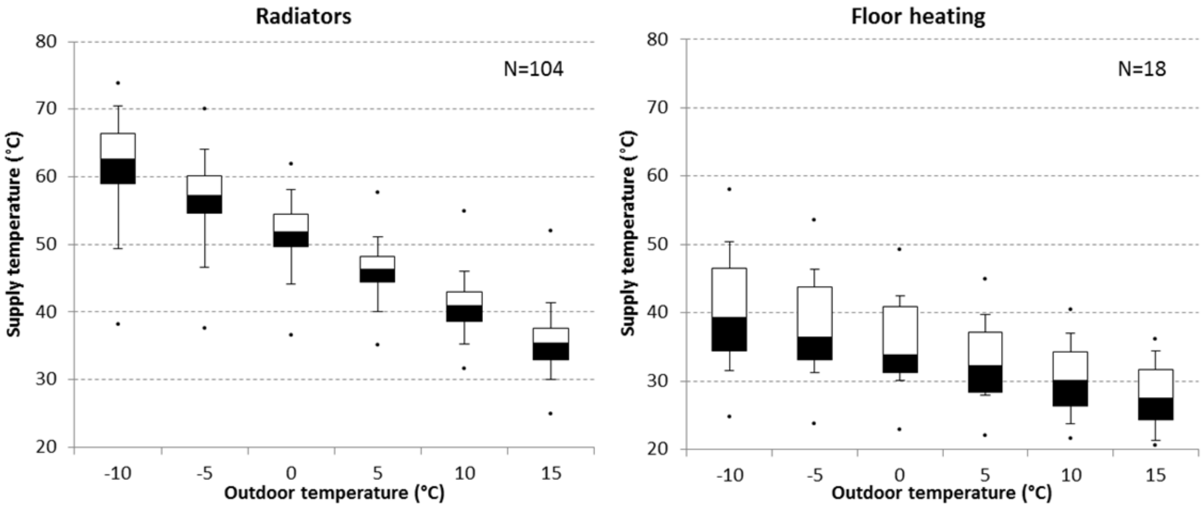


Figure 29. Supply temperature vs. outdoor temperature in case of radiators (104) and in case of floor heating (18) (min and max, 1st and 9th deciles, 1st and 3rd quartiles, median). From linear regressions on hourly values.

Concerning heating by air ventilators, the supply temperature is generally constant at 50°C, but could be in some specific cases lowered to 25-30°C.

In Figure 30, the supply temperature at -5°C is plotted versus the year of construction of the building. A clear trend of decreasing temperature levels is observed from the 1980s, probably linked to improving the heating systems' technology and to introducing standards. The few examples of renovated buildings tend to indicate a decrease in supply temperatures following renovation.

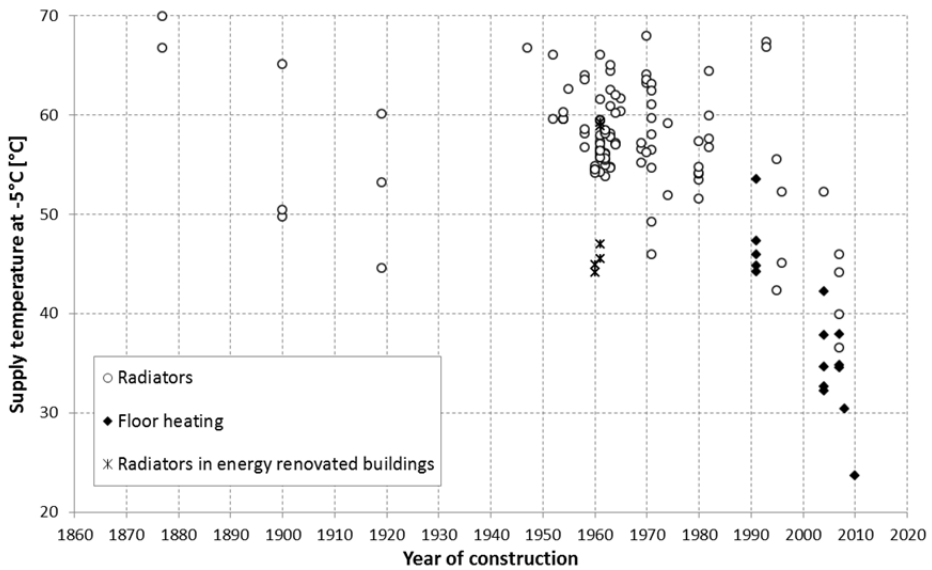


Figure 30. Supply temperature for ambient temperature -5°C (radiators and floor heating systems) vs. building age. From linear regressions on hourly values.

Supply temperatures at -5°C ambient were compared to the building annual thermal demand (including both SH and DHW) in kWh/m^2.yr (see Figure 31).Lower supply temperatures are generally observed in buildings with low thermal demand equipped with floor heating systems, while buildings with high thermal demand show higher supply temperatures. This trend is probably closely linked to the building's age.

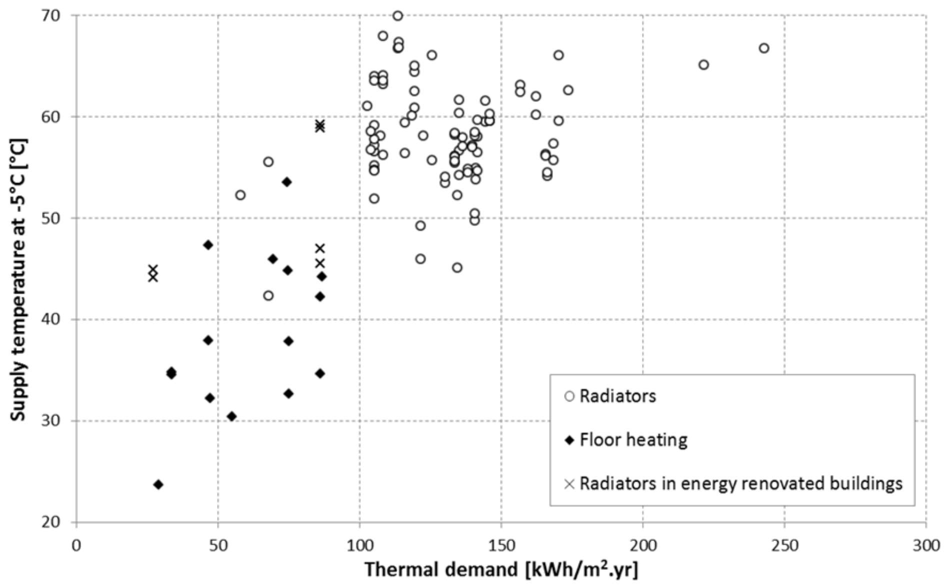


Figure 31. Supply temperature at -5°C ambient vs. total thermal demand (SH+DHW). From linear regressions on hourly values.

The importance of managing the supply temperatures in a building connected to a DH system is widely accepted by DH customers. However the problem of lowering the return temperatures is hardly addressed, whereas it is at least as important as lowering the supply temperatures in the cases of using heat pumps or solar heat for example. This issue is however highlighted in the “District Heating and Cooling Connection Handbook” (Skagestad et al. 2002), which provides guidance for the connection of existing buildings to district heating and cooling systems.

Figure 32 presents the relation between supply and return temperatures at -5°C ambient on the set of buildings studied in Quiquerez et al. 2013.

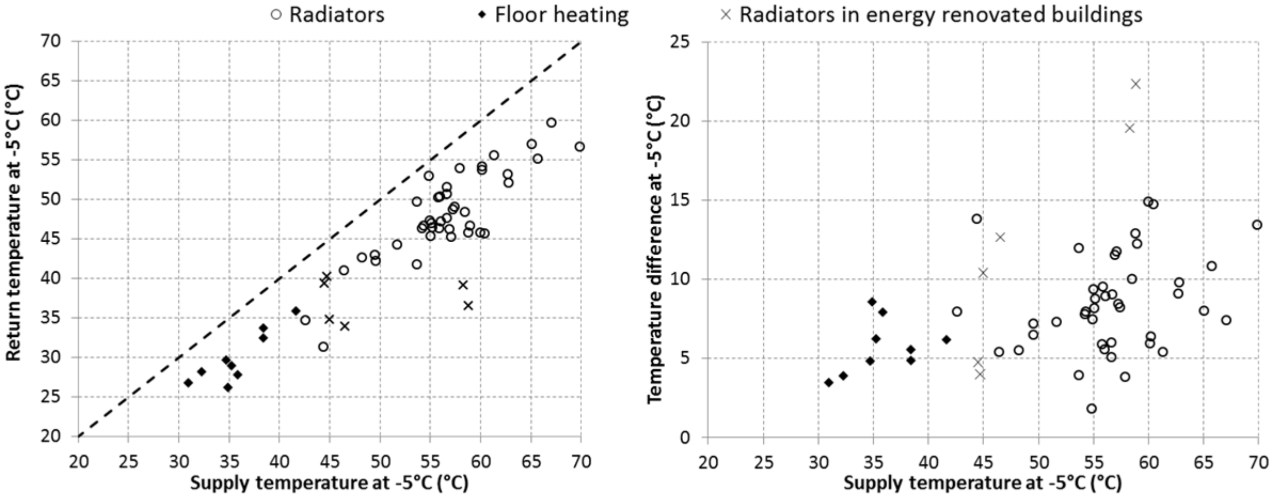


Figure 32. Supply vs. return temperature at -5°C ambient (left). Temperature difference between supply and return vs. supply temperature at -5°C ambient (right). From linear regressions on hourly values.

The return temperature at -5°C ambient lies between 25 and 60°C depending on the supply temperature and the type of emitter. The temperature difference between supply and return is mainly between 5 and 10K at -5°C ambient; this is lower than what could be achieved. This is caused by overflows due to bad hydraulic balance and/or oversized circulation pumps. Until now, no effort has been made to decrease return temperatures, because most of the buildings are supplied by individual boilers or DH at high temperature. The renovated buildings could reach a higher temperature difference if the heat distribution is optimized.

As the flow into the building is generally constant, the temperature difference across the heat exchangers in the substations decreases when the outdoor temperature increases (see Figure 33). The temperature difference in the heating circuit at -5°C ambient is not significantly different in the case of radiators (6-10K) than in the case of floor heating (5-8K). However, the maximum values can be larger in the case of radiators (e.g. above 20K at -5°C ambient) than in the case of floor heating, due to the fact that the supply temperature is much higher. The median decreases linearly from 9K at -10°C to 2K at 15°C in the case of radiators and from 7K at -10°C to 2K at 15°C in the case of floor heating.

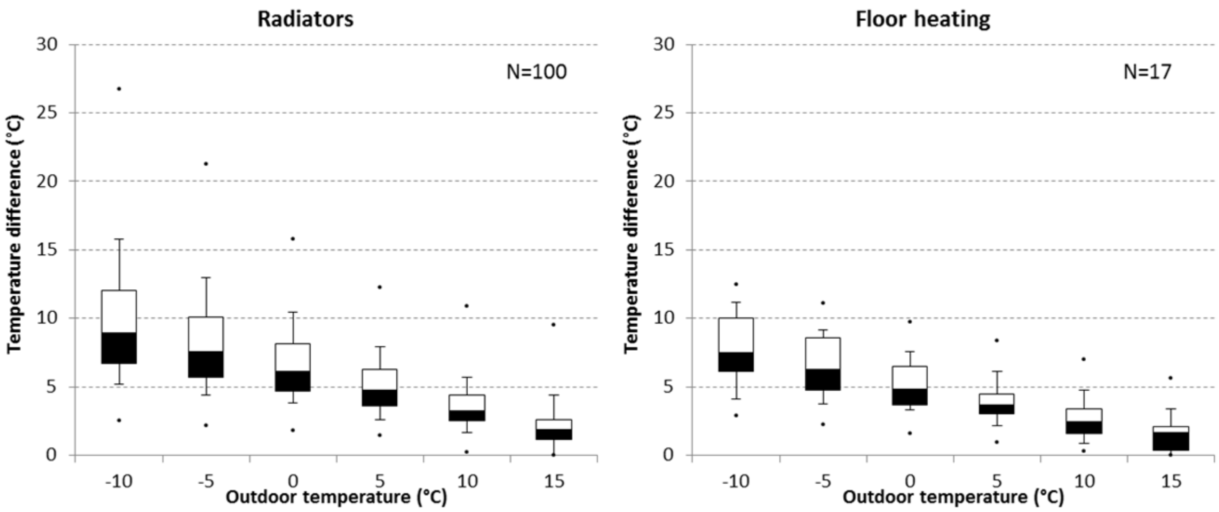


Figure 33. Temperature difference between supply and return vs. outdoor temperature in case of radiators (100) and in case of floor heating (17) (min and max, 1st and 9th deciles, 1st and 3rd quartiles, median). From linear regressions on hourly values.

Space heating can be adjusted by a night set-back allowing the internal air temperature to fall during the night. Depending on the buildings' thermal mass, this function can result in energy savings. This control strategy can allow the network supply temperature to fall during the night; however it contributes to increasing the heat load variability (Frederiksen et al. 2013) with a higher peak demand in the early morning.

In Quiquerez et al. 2013, 90% of the studied buildings utilized a night set-back on DH supply temperatures lying between -5K and -20K. The set-up time in the buildings equipped with radiators is usually between 5:30 and 6:00 a.m., while the set-back time is around 9:30-10:00 p.m. As the inertia is larger in buildings heated by floor heating, set-up and set-back times are generally earlier, typically between 4:30-5:30 a.m. and 8:30-10:00 p.m. respectively.

In buildings with two distribution loops (orientation North-South), supply temperatures can be regulated differently in order to take into account solar gains. The difference in supply temperatures observed between North and South distribution loops is generally low (<5K at the design outdoor temperature).

Even with the appropriate technical equipment (control units, thermostatic valves, variable speed pumps, correctly designed radiators), the optimal operation of the heat distribution system is closely linked to how it is used, which includes inhabitants' behavior (eg open windows, thermostatic valves) and operators' practices.

District heating systems sometimes supply sorption chillers for producing chilled water for air conditioning of buildings. An overview of the technical solutions is available in the Summerheat project report (Summerheat 2009).

In this type of system, the supply temperature has to be higher than 80°C most of the time, and the current economic limit is close to 90°C. The required temperature level for sorption chiller applications is thus inconsistent with the objective of lowering the DH supply temperature below 65°C. Similarly, the heat process is out of scope (see limitations in chapter 1.2).

4.1.2 Domestic Hot Water (DHW)

The temperatures required for DHW preparation are principally driven by the prevention of legionella generation. Production at 55-60°C is internationally considered as usual (see chapter 3.1 from Dalla Rosa, 2014).

One example of a regulation that tries to balance energy efficiency with caution regarding legionella is the Swiss standard for DHW (SIA 2011), whereby DHW stored at a temperature between 25 and 50°C for a duration exceeding 24 hours before being used has to be thermally disinfected (i.e. heated at 60°C for one hour). This requirement does not apply to instantaneous hot water heating systems. In all cases, the maximum temperature in the distribution pipes is limited to 65°C.

The temperature levels for DHW production mentioned in this section are all observed values in existing buildings, stemming from diverse monitoring campaigns on residential buildings in Geneva (see Table 3).

Table 3. Characteristics of 5 residential buildings providing DHW in Geneva.

Building No.	Reference	Location	Type	Year of construction	Surface	Monitoring period
1	Mermoud et al. 2014	Geneva	New, Minergie standard	2010	9'600 m^2	2010-2012
2	Zgraggen	Geneva	New, Minergie	2004	4'600 m^2	2004-2008

	2010		standard			
3	Mermoud et al. 2012	Geneva	Renovated, Minergie standard	1963 (renov. in 2008)	5'400 m^2	2008-2010
4	in progress	Geneva	Renovated, Minergie-P standard	1952, (renov. in 2013)	7'300 m^2	2014-2016
5	in progress	Geneva	Non-renovated	1964	33'500 m^2	2014-2015

Unlike space heating supply temperatures, DHW supply temperatures are not dependent on the outdoor temperature (a constant value is generally observed). In Figure 34, the different levels of temperature mentioned in Table 4 (also plotted in Figure 35) are located on a general scheme.

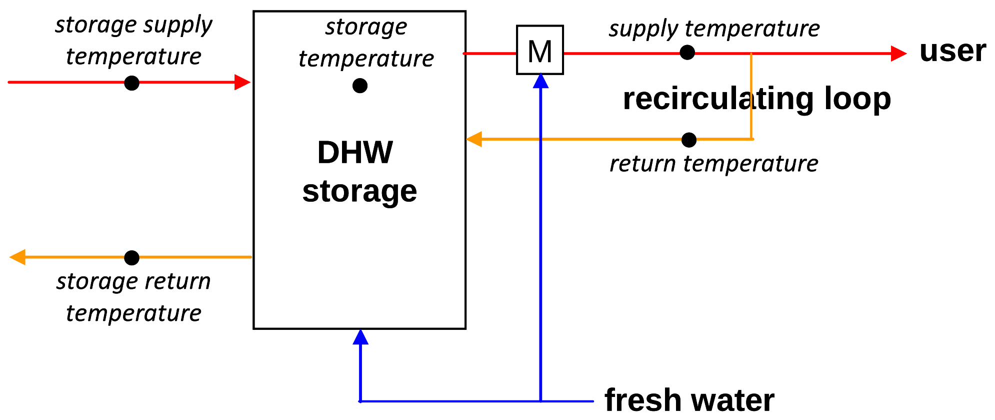


Figure 34. Location of the sensors in the DHW production systems.

Table 4. Temperature levels observed within the DHW production system of 5 existing buildings (hourly values).

Building No.	Distribution	Storage charge profile	storage T°	storage supply T°	storage return T°	supply T°	return T°
1	Decentralised storage in flats	1/2-2 hrs 3-4 times/day[1]	UN	55-60°C	35-50°C		
2	Recirculating loop	all day[2]	45-60°C	UN	UN	45°C	30-40°C
3	Recirculating loop	all day[2]	50-65°C	70-80°C	40-60°C	45-55°C	30-40°C
4	Recirculating loop	all day[2]	45-50°C	40-55°C	20-50°C	UN	UN
5	No loop	all day[2]	50-65°C	55-75°C	40-65°C	UN	

[1]once one of the individual boilers is empty
[2]once the storage is empty
UN: unknown

No clear trend appears regarding the building age. The storage supply temperature is generally not controlled but given by the production (e.g. for building No. 3, it is 70-80°C as supplied by the district heating).

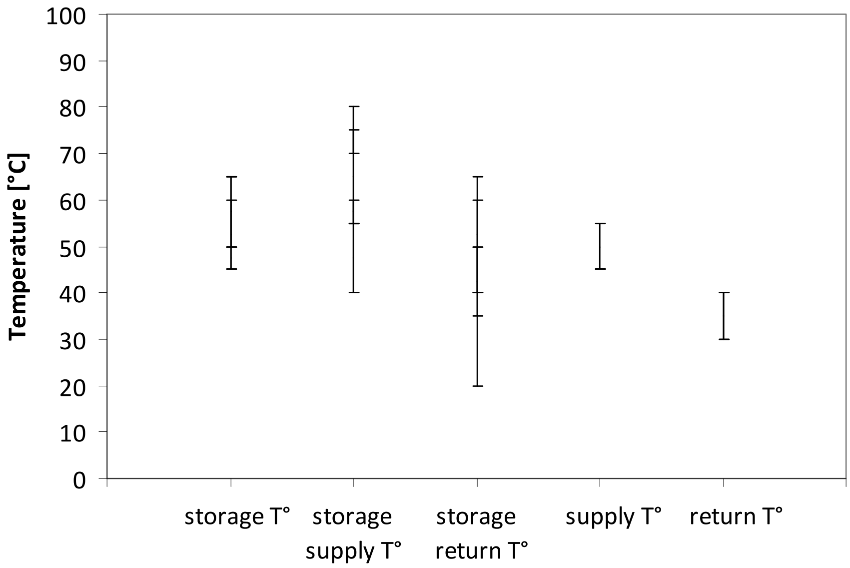


Figure 35. Temperature range observed at various points of the DHW production systems.

The observed storage temperatures lie between 45 and 65°C, and the storage supply temperatures between 40 and 80°C for a DHW supply between 45 and 55°C.

DHW production often implies higher supply and/or return temperatures than space heating because of legionella risks. Therefore the DHW production profile may influence the required supply/return temperature on low temperature DH systems.

Most of the time, DHW is produced in the building once the storage empties. However a different strategy is sometimes adopted by limiting the possibility of DHW production to definite periods in the day (e.g. 2 hrs in the morning and evening). This favours low heat network temperatures because the DHW demand is cut off most of the day and permits the use of low temperature heat such as solar or waste heat. The volume of DHW storage determines the possible strategies of DHW production (instantaneous, accumulation or semi-accumulation).

Lowering the return temperature can also be achieved by pre-heating the fresh water with the return flow from the SH circuit, before heating to the required temperature with the supply flow. Different substation layouts are proposed in Frederiksen et al. 2013.

4.2 Reduction of current temperature levels

The building stock currently undergoes different transformations which may impact the temperature levels in customer heating systems.

4.2.1 Space heating

Improving the building envelope reduces the heat demand and thus allows a potential decrease in the supply and return temperature. The distribution temperatures in two residential buildings (adjacent and identical) from the 1960s of which only one was renovated in 2008 are presented in Figure 36:

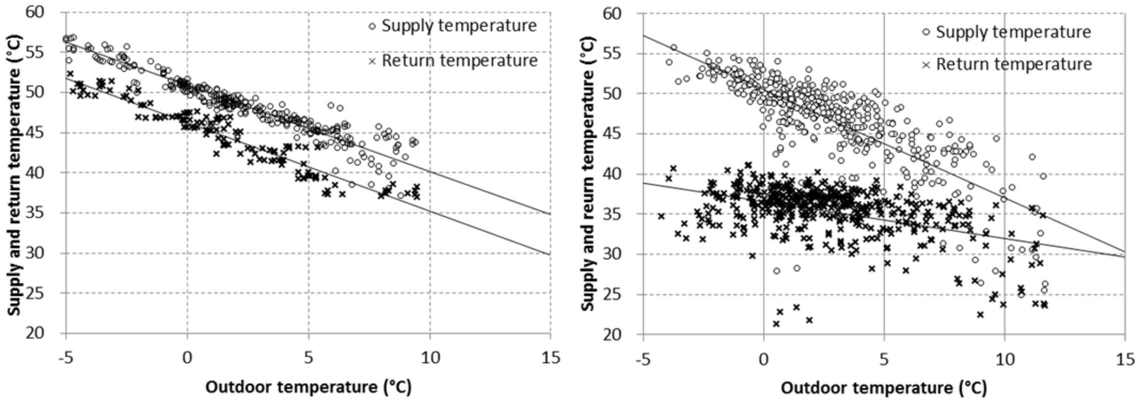


Figure 36. Distribution temperatures vs. outdoor temperature in the non-renovated (left) and the renovated (right) building. Hourly values, 10.01-16.02.12 (left) and 01.02-28.02.09 (right).

This example shows that the renovation of the building envelope does not automatically result in a reduction in the supply temperature if no attempt is made to optimize the heat distribution. However the return temperature has been lowered since the oversized circulation pumps were replaced with smaller ones. The lower flows induced higher temperature differences between supply and return, from 5K up to 20K (with a return temperature lower than 40°C all year).

In order to achieve a lower return temperature from SH distribution, one key point is to deliver the heat with a controlled flow. Adjusting the flow rate to the demand requires a good hydraulic balance of the distribution circuit, which is generally not the case in old buildings, resulting in higher flows and/or supply temperatures in order to ensure thermal comfort even in poorly balanced (low flow) zones. Performing hydraulic balancing in a building enables the flow to be shared in each radiator, and typically reduces the total flow in the heating circuit. Electricity savings can be achieved since (i) the electricity consumption of a pump grows with the flow (ii) the circulation pumps often run during the heating season.

Figure 37 presents the distribution temperatures in a building before and after hydraulic balancing. The fixed speed circulation pump was also replaced by a smaller and variable speed pump.

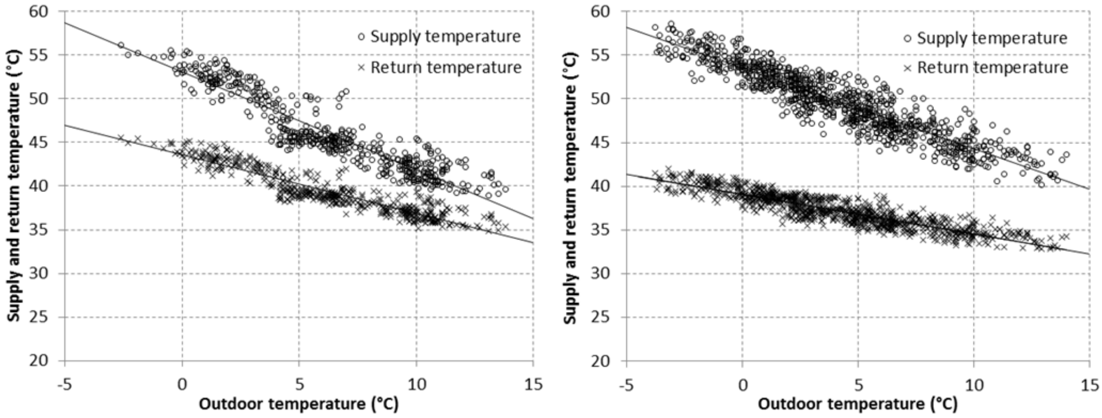


Figure 37. Distribution temperatures vs. outdoor temperatures before (left) and after (right) hydraulic balancing in an existing building. Hourly values, 06.11-10.12.12 (left) and 11.12-22.02.13 (right).

In this building, the poor thermal envelope (which has not been renovated) did not enable the supply temperature to be reduced, however the lower flows resulted in a decrease of the return temperatures, to below 40°C all year.

The presence of thermostatic valves also results in lower flows in the distribution system since the flow to the radiator is stopped as soon as the set-point is reached.

The share of thermostatic valves is very different from one country to another (Boverket 2010, EPISCOPE 2014): in individual housing it is 41% in France, 62% in the United Kingdom, and 96% in Sweden; in collective housing it is 24% in France, 43% in the United Kingdom, and 94% in Sweden. 80-90% of the Swedish tertiary buildings are equipped with thermostatic valves. In Norway, nearly 100% of all heating systems use thermostatic valves or similar/better equipment for temperature control (in particular for electric heating). In the UK nearly 100% of radiators are controlled by thermostatic valves in public buildings but are often performing very poorly (Liao, 2005).

In the renovated building illustrated in Figure 36, hydraulic balancing was performed 3 years after the envelope renovation, allowing the effect of each action to be isolated.

Figure 38 presents the temperature levels before and after the hydraulic balancing in the renovated building.

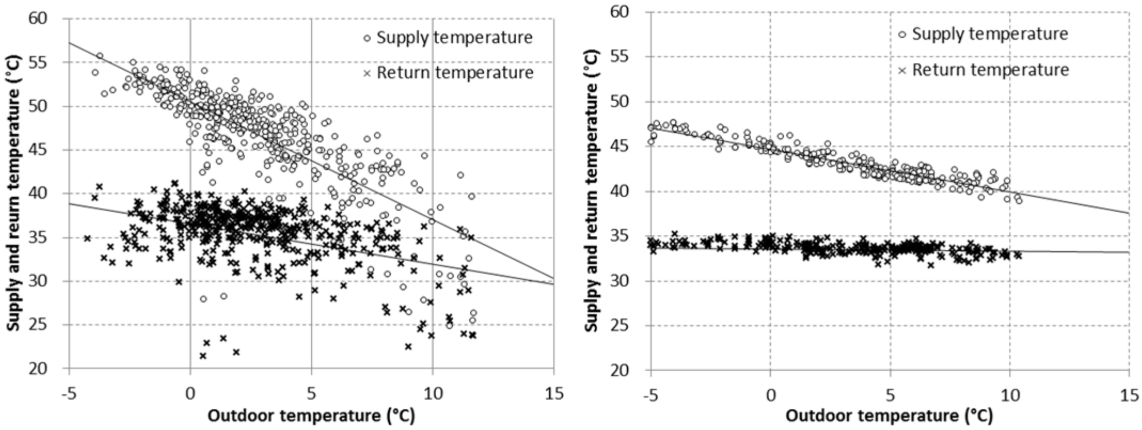


Figure 38. Distribution temperatures vs. outdoor temperatures before (left) and after (right) hydraulic balancing in a renovated building. Hourly values, 01.02-28.02.09 (left) and 16.01-08.02.12 (right).

The hydraulic balancing allowed a lower supply temperature (from 55-60 to 45-50°C at -5°C ambient). The combination of both envelope renovation and hydraulic balancing enabled the decrease of the supply temperature (lower than 50°C all year) and of the return temperature (lower than 35°C all year).

4.2.2 Domestic hot water

Health constraints, especially to prevent legionella development, require the DHW temperature to be maintained at a high enough level if stored before use.

Three strategies are adopted following the particular regulation in each country (Dalla Rosa, 2014): (i) DHW production and storage at a temperature higher than 55°C to avoid the proliferation of legionella (ii) temporary overheating (e.g. 1-2h everyday) of the storage tank at 60 to 70°C, involving higher supply temperatures (iii) instantaneous DHW production without long-term storage. (see as well chapter 5.1.1)

Experiments were made in low-energy individual dwellings connected to low temperature DH in Denmark supplied with DHW at less than 50°C (Christiansen et al 2012). The legionella risk is controlled by means of instantaneous production without storage before distribution. The tests have given positive results with no acceptability problems or complaints from the users. The validity of the concept has to be confirmed for collective buildings, considering that a permanent circulation of DHW inside the building is generally required to allow immediate distribution of hot water to every user.

It has also to be noted that it is not compatible with decentralized solar water heating for which a storage tank is necessary.

4.3 Survey of customer heating system temperature demands

A survey (Appendix A) was devised in order to obtain information from a range of DH systems internationally. The purpose of the survey was to determine at a much higher level of resolution than has been the case, operational temperatures of customer heating systems. Specifically, it focused on flow and return temperatures *at the customer heat emitter (most commonly radiators) level.*

The survey contained two parts:

- data on current temperature levels at the radiator (or other heat emitter);
- speculation by the respondent on the potential for, and barriers to, supply temperature reduction.

The survey was distributed first through a major district heating association, and subsequently through direct contact with the help of the nominated project IEA-DHC Experts and through other direct in-country contacts.

The wide distribution of the survey through the district heating association was an attempt to draw responses from as wide a population of systems as possible. However, when this failed to produce responses, direct contacts were made. This approach produced a small number of responses, and several more were promised but did not materialize.

As a final attempt to secure wider information, a much shorter survey was produced by condensing the original survey. When this also failed to produce a result, it was concluded that the most likely reason is that this information is not routinely collected.

There follows a discussion of the limited results that were forthcoming, but perhaps the most important observation to be drawn from this exercise is that there appears to be a gaping hole in terms of available data. Although overall system flow and return temperatures may be known, more detailed information about customer radiator temperatures is not. Yet information about radiator temperatures can benefit all DH systems, and the behaviour of the radiator (or other heat emitter) is fundamental to a successful transition from a higher to lower overall system temperature, from 1 or 2GDH to 3GDH, or from 3GDH to 4GDH.

4.3.1 Survey results

The survey produced only a small number of responses, from three different countries. Nevertheless, some useful further information was received from those who did respond.

The systems for which the survey form (Appendix A) was returned were achieving overall system winter supply and return temperatures of 85 to 90°C and 40°C to 55°C. In the summer supply temperatures were 65 to 75°C with return temperatures in the mid-40s.

One UK system ideally operates with 94/55°C supply and return but states that this is difficult to achieve due to the customer connections still designed for the old 82/71°C regime, while another system serving new build operates at 85°C supply temperature in winter and 75°C in summer.

Two advanced case study exemplars from Scandinavia (one from Sweden and one from Finland) are both now achieving the following:

- radiator systems operating with supply temperature 45 – 50°C and return temperature 30 – 35°C
- underfloor heating systems operating with supply temperature 30 - 35°C and return temperature 25 – 30°C

One system in Finland has recently introduced such lower temperatures for radiators as recently as 2014; prior to this the radiators were designed for 70/40°C operation.

One system in the UK reported that, although the intended supply and return temperatures are 70/40°C for systems serving new buildings, they are in practice not easily achieved due to old practices of installation leaving return temperatures much higher. In order to combat this trend the system introduced 20% discounts for customers consuming over 100MWh per annum who manage to achieve a return temperature of 55°C or better.

Another UK system serving new build dwellings is set for 65°C supply and 40°C return.

The case study examples each had DHW being delivered at 60°C (Scandinavia) with a return temperature of 40°C; and supply temperature 65 – 70°C (UK).

4.3.2 Specific questions focusing on the potential for lower temperature systems

What are the factors for choice of supply temperature?

Respondents set out two distinct themes. The first was following practices that are based variously on recommendations, regulations, or good practice. These included national focus group recommendations, and following international best practice (particularly from Sweden).The second was that standard design practices that were still being followed may not now be appropriate (eg applying supply and return temperatures that were devised for early boiler systems), for example the UK standard practice of 82/71°C.

Additionally, one respondent also expressed that it may be preferable, where the demand for heat is increasing, to raise the supply temperature rather than have to increase the flow or have to replace the pipes.

Another pointed out that the supply temperature rests with the actual demand for heat, and also specifically the best understanding of DH combined with what developers will accept for domestic systems.

What prospect is there for supply temperature reduction?

Respondents had considered this issue. There was a range of opinions, from feeling that the scope for supply temperature reduction is rather limited, to this being an important consideration for connection of new buildings.

Of paramount importance is that it must not impair customer satisfaction in any way. It can only be done in small steps and only with full customer support, but considering the current way the DH system and customer equipment works, this is not easy.

Hence there is a gradual reduction of temperature supply taking place at one system: this started at 95°C and then reducing by 1°C per year for 5 years, always ensuring customer satisfaction is maintained.

Also, at one system discounts of up to 20% have been introduced for customers using over 100MWh per annum if they can achieve sufficiently low return temperatures

In emergent countries there is plenty of scope for temperature reduction but the knowledge base for engineers may need to be improved. Furthermore, while technically it would be possible, contractually it may not be acceptable unless there is sufficient confidence in future performance.

What are the barriers to supply temperature reduction?

One respondent felt that delivery of heat at system capacity would be compromised. Consequently the needs of customers, and associated contractual commitments, were a matter of concern. The level of heat demand would need to be reduced, for instance through improved design of domestic systems. However, there are also customers who have existing equipment that requires a high temperature differential; only new equipment can function with reduced temperature difference. One major customer (a dairy) mentioned requires water at 90°C for pasteurization (although only for a short time each day). So the respondent questioned whether it is possible to handle both new and old customers in an equivalent way.

What could be done to remove the barriers?

Respondents referred to the need to improve HIUs and sub-stations; the need to analyze entire systems including all those involved in the DH system and its consumers, and also to re-negotiate contracts with all parties.

The need for education of service engineers in emergent markets was also mentioned, as was the need for more energy efficiency measures generally.

4.3.3 Interviews with district heating practitioners and researchers

Interviews took place with two UK experts both of whom pointed out that poor performance is often encountered in existing DH systems because the customer heating systems are not balanced and flow rates not optimised. Simple measures can lead to significant improvements.

First, a meeting took place with an energy consultant who had been involved in a research project that included a series of laboratory tests that were carried out to simulate typical UK district heat network customer heating systems.

Specifically, the radiators were initially set up at their maximum flow rate and with no flow control, their lockshield valves fully open; a situation that the respondent felt occurs not infrequently in existing UK systems.

A typical UK apartment has a heat demand of approximately 4kW. During this test, with the pumps running flat out, flow and return temperatures were approximately 70/63 °C respectively, and the required 4kW demand was secured.

However, the test then proceeded further and just by turning the pump to a lower speed the flow and return temperatures were significantly improved to 69/50 °C with no detriment to the output.

A further discussion then took place with a local authority expert who is responsible for a range of heat networks including older networks established in the 1960s and 70s, and also new systems serving new-build properties. He referred to customer heating system operation and set-up that he had observed, drawing on both district heating and individual boiler system to illustrate his points.

He believes that many people are currently using TRVs in the wrong way, just setting them to maximum flow. Hence heating systems are not optimally balanced. If the system is rebalanced, TRVs do help to obtain a better return temperature. For example, he has seen that even old legacy district heating systems operating at 82/71 °C have been improved to 82/67 °C with the addition of properly configured TRVs.

He also mentioned that the actual configuration of the radiators often impairs performance with sub-optimal top-entry bottom-exit radiators commonplace.

Consequent poor overall system performance often leads people to turn up the boiler temperature. The boiler then does not condense. He suggested one solution would be for a TRV on one side and a flow limiter on the other side (of course, then there are 2 valves per radiator).

New radiators are designated 70/40 °C. However, fitters often do not set the flow rates. He has observed examples from new-build systems of radiators are not being properly balanced with anecdotal observation of lockshield valves not being adjusted, but left completely open at maximum flow rate.

He has also observed TRVs installed the wrong way round. Use of bi-directional valves as a flow selection feature would mean that correction could be carried out without removal.

Following chance meetings at a DH conference, researchers from Scandinavia explained project work they had been carrying out on radiator temperatures.

One of the researchers had compiled radiator temperature data for 109 different systems in Gothenburg; these revealed some interesting insights (Jangsten M, 2016). When the ambient temperature is 0ºC, the average flow temperature to the radiators is 47.4ºC and the average return temperature 34.5ºC; hence demonstrating well-controlled customer internals consistent with a low temperature approach and achieving respectable return temperatures.

However, the data also exhibits a substantial range, such that the delta-T between flow and return ranges from almost 25ºC down to less than 4ºC, with return temperatures falling between 24ºC and 44ºC.

Hence although the data suggests good overall performance of the customer heating systems, with the best systems outstanding, there is nevertheless a significant proportion of poorer performing systems which would benefit from further investigation. It is likely that only with this kind of detailed monitoring can the poorer performing systems be pin-pointed.

4.4 Conclusions about customer temperature demands

The outcome from the survey suggests that little is known about or considered in relation to customer radiator temperatures. The authors believe that there is a strong case for carrying out targeted research to investigate this, probably by means of actual system monitoring, because the behaviour of the radiator (or other heat emitter) is fundamental to successful system transition from 1 or 2GDH to 3GDH, or from 3GDH to 4GDH.

Fortunately, detailed research has been carried out in one country (Switzerland), enabling an understanding that there is significant potential for decreasing customer temperature levels by optimizing the heat distribution in buildings. However, the production of DHW at 50-60°C remains problematic. Some early recommendations can be made.

4.4.1 Decrease of the temperature levels for space heating

Concerning the heat emitters:

- Keep the current radiator size (even if oversized) in existing buildings when envelope refurbishment takes place; this will enable heat distribution at lower temperatures and flow rates.
- Introduce floor heating in new buildings when possible.

Concerning the flows:

- Replace the fixed speed distribution pumps with variable-speed pumps, permitting lower flow rates and return temperatures.
- Remove unnecessary by-passes (typically in buildings that were supplied before by old individual boilers and therefore had to maintain a high return temperature to avoid corrosion)
- Perform hydraulic balancing of the heat distribution circuit and/or add thermostatic valves to avoid unwanted overheating of certain zones, enabling lower supply and return temperatures and flow rates.

4.4.2 Decrease of the temperature levels for domestic hot water production

- If possible use instantaneous production (without storage thus at lower temperature), implying longer thermal lengths in substation heat exchangers.
- If the latter is not possible (e.g. in case of solar pre-heating), a decentralized booster in substations allows heat supply by the DH system at middle-range temperatures.
- Adopt hydraulic schemes in substations that allow the lowest return temperature possible, maybe by imposing new standards for substations.

4.4.3 Organizational aspects

The heat/cold distribution inside a building or a single house (secondary circuit) that is connected to a thermal network (primary circuit) can be managed directly by the DH provider, by a building operator or by the owners themselves. If the primary and secondary circuits are not managed by the same entity, the DH provider will have to agree with the customers a set of distribution temperatures and flows that are compatible with both the primary and secondary circuit requirements.

This task can easily become complicated if every building has a different management system, and more so if the building operator/manager has no interest in optimising the distribution temperatures for the benefit of the network. However, owners could be interested in lowering their distribution temperature in order to increase the energy performance of their building.

The problem of controlling the supply and/or return temperatures is sometimes addressed in the contract between the DH provider and its customers. In this case, the contract defines the temperature range that should be adhered to by the building operator, as well as the consequences of non-conformity. The consequences can either be a series of penalties or defined by a system of bonus/malus.

The survey had a low rate of responses/feedback. Similarly, in situ monitored data of distribution temperatures (supply and return) in buildings' heat emitters has not been found in general literature outside the Swiss study mentioned here. This absence of literature suggests this type of data is badly documented. Future research on in situ monitoring data of distribution temperature in buildings can fill this gap, and assist the understanding of the interactions between the two circuit managers. It could also show cultural differences and /or similarities between countries.

5 Future temperature levels

5.1 Expected temperature levels in future 4GDH systems

The design philosophy in 4GDH is to try to push the lower limit for network supply/return temperatures to 55°C/25°C and in general try to lower the temperatures in the network as much as possible throughout the whole year. The transformation process should take into consideration the additional cost due to increased heat exchange area and control units and temperature boosters (direct electrical heaters and heat pumps). The temperature level in the 4GDH system is defined as a range between 50°C -55°C in summer to 60°C -70°C in winter for supply temperature, and 25°C -30°C in summer to 40°C in winter for return temperature (Olsen et al 2014). With a local temperature booster, a lower system supply temperature down to 30°C -40°C is possible. For floor heating or wall heating systems, the supply temperature can be just a few degrees higher than room temperature. In such cases, the return temperature can be cooled down to 20°C-22°C (Lund et al 2014).

5.1.1 Temperature constraints in DHW

The temperature constraints for DHW preparation come from the concern of hygiene and thermal comfort. In general, the temperature used to meet the hygiene requirement is higher than that for the thermal comfort. The hygiene issue is to prevent Legionella multiplication. The optimal temperature for Legionella proliferation ranges between 25°C to 45°C. Slow decimation starts when the water temperature is above 50°C. A minimum DHW temperature is required to avoid the risk related to Legionella bacteria and growth of amoebae and other microorganisms in the potable water system. The temperature regulations to avoid Legionella risk are different between different DHW systems and different countries (Dalla Rosa et al 2014).

A DHW substation may include a heat exchanger and DHW storage unit, pump, thermal and hydraulic controllers and circulation loop. There are two typical types of DHW substations used in DH: storage tank units and instantaneous heat exchanger units (IHEU).

DHW systems should fulfill the requirement for hygiene, thermal comfort, effective cooling and good energy efficiency. The DH supply temperature is constrained by the hygiene and thermal comfort requirements, whereas the DH return temperature is a consequence of the following:

- Cold water temperature
- The circulation set-point temperature for DHW systems with circulation

- Bypass flow from DH supply to DH return for quick supply of DHW at a comfortable temperature for IHEU systems
- The efficiency of the heat exchanger between the DH and DHW.

IHEUs use a plate heat exchanger to exchange heat with DH water and produce DHW instantly. There is no temperature requirement for IHEUs if the water volume from the heat exchanger to the tapping point is small. According to the German Standard W551, it states that there is no risk of Legionella multiplication when the total volume in a DHW system from the heat exchanger to the tapping point can be kept below 3L. The concern for temperature levels in an IHEU comes from thermal comfort point of view. In the Danish standard, the comfort DHW temperature at the fixtures is between 40°C-45°C (DS 439 2009). In low-temperature DH application, heat exchangers with increased heat transfer area and enhanced turbulence can produce DHW at 47°C with the primary DH supply temperature at 50°C.

Traditional DHW storage tank units need to be heated to 60°C to avoid Legionella risk. Accordingly they have to be replaced by IHEUs in order to implement 4GDH. The heat exchanger is designed according to the peak DHW demand. In this way, the DH supply temperature to the building at 50 -55°C can produce DHW at 47°C.

For the DHW system with circulation, the water temperature should be no lower than 50°C in all distribution lines. In 4GDH, the circulation pipe in single family houses can be eliminated with properly designed DHW installations. In multi-storey buildings, due to large water volumes in the vertical risers, horizontal distribution pipes and circulation pipes, the DH temperature at 60-65°C is required for supply of DHW at 55-60°C. However, the circulation pipe in multi-storey buildings can also be eliminated. Such solutions include installing a flat station in each individual apartment, or applying electric tracing to keep the supply line above 50°C.

5.1.2 Temperature constraints in space heating

The DH supply temperature constraints for space heating depend on the type of heating devices, the building heating demand and the connection scheme between network and the building (indirect or direct system).

Heating systems are normally designed for room temperature of 20°C. The design peak load is typically based on a nationally defined very low outdoor temperature. The calculation of the design peak load is typically made without the effect of heat gains. Accordingly the actual heat demand during the year is much smaller than the design load.

New buildings typically have radiant heating systems which are ideal for low temperature operation of DH systems. Radiant heating devices like floor, ceiling, or wall heating have a large heating surface. The dominant part of the heat transfer is through radiant heat transmission which accounts for 50-70% of the total. For such devices, a small temperature difference can deliver the required heating power to the room. The district heating supply temperature need to be only a few degrees above the consumer thermal comfort temperature. Thanks to the small temperature difference between room air and the heating elements, radiant heating devices can regulate the heating output through the 'self-regulating' effect (Karlsson, 2008). When a sudden heat gain is imposed like solar gain, the temperature difference between room air and the heating element decreases which reduces the heating output instantly.

For low density areas with new nearly zero energy buildings which have a low use for heating ultra-low temperature DH in combination with heat pumps or direct electrical heating of DHW can be economically optimal. The buildings may be heated by a floor heating system or heated and cooled by a combined heating and cooling ceiling with one common water system. Such a system requires heat to be supplied at only a few degrees above the room temperature to heat up the room in a self-controlling way.

Existing buildings typically have space heating based on radiators. Radiators made of steel or cast iron can work at high temperatures. These are suitable for less well insulated buildings with a high peak load and annual heating demand. Old radiators in the UK were designed based on standard BS3528 (British standard 1977):a supply temperature of 90°C, return temperature of 70°C at room temperature 20°C. As a replacement of convective type space heaters, the standard EN442 (European standard 1996) specifies the radiator design supply temperature at 75°C, return at 65°C at air temperature 20°C. This temperature level suits 3rd generation DH networks. A lower radiator design temperature is sufficient for current design practice. For example, in Danish Standard DS469 (Danish standard 2013), the design temperature level is 60/40/20°C (supply/return/air temperature). Furthermore, radiators can work in low temperature systems by means of an enlarged heating surface or with an add-on-fan blower (Johansson et al 2010).

Weather compensation curves can be used to adjust supply temperature. Figure 39 shows temperature compensation curves for different building and radiator types (Brand et al 2013). The radiators for the building are designed based on temperature levels of 70°C /40°C /20°C.

The original building is a typical Danish single-family house built in the 1970s (corresponding to the non-renovation case). The same building underwent light and deep renovations which corresponds to the new window case and the extensive renovation case. In most of the cases, the maximum flow rate is limited to 264 L/h for the SH system. An exceptional case is the non-renovated 22°C 'High Flow case', for which the flow rate through the radiator can be unlimited. Two room air temperature levels are simulated at 20°C and 22°C.

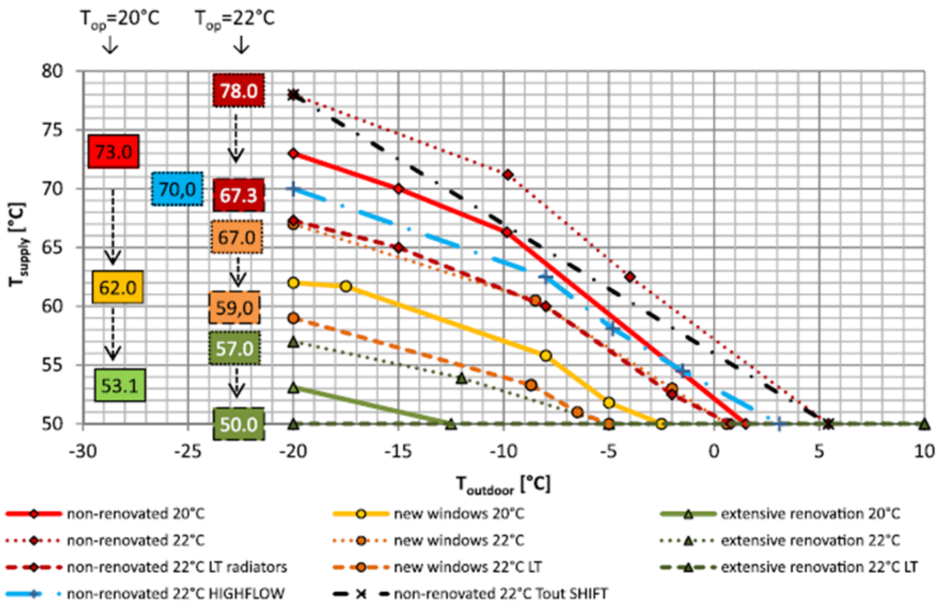
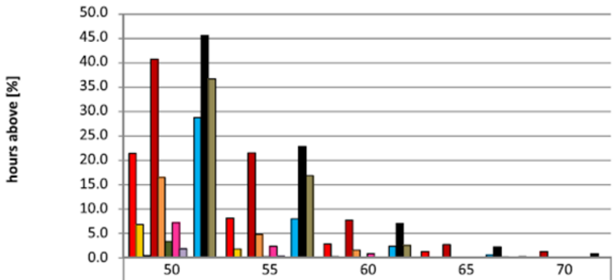


Figure 39. Radiator supply water compensation curves for different levels of renovation of the investigated building.

According to the temperature compensation curve, the annual DH supply water temperature for different types of buildings and heating systems is illustrated in Figure 40. It can be seen that when the non-renovated building is at a room air temperature of 22°C, the SH supply water temperature exceeds 50°C for 41% of the annual time, above 60°C for 8% of the time and for only 1% of the time does it need to exceed 70°C. For the same building but with a lower set-point temperature, these annual percentage times drop to 22% for temperatures above 50°C, 3 % for temperatures above 60°C, and 0.2% for temperatures above 70°C. For existing buildings, low-temperature DH supply is sufficient for the majority of the heating season. In cold winter periods, the DH supply temperature can be increased for brief periods close to 70°C.



	50	55	60	65	70
non-renovated 20°C	21.4	8.1	2.9	1.3	0.2
new windows 20°C	6.8	1.8	0.2	0.0	0.0
extensive renovation 20°C	0.4	0.0	0.0	0.0	0.0
non-renovated 22°C	40.8	21.5	7.7	2.7	1.2
new windows 22°C	16.5	4.8	1.6	0.1	0.0
extensive renovation 22°C	3.4	0.2	0.0	0.0	0.0
non-renovated 22°C LT radiators	7.2	2.3	0.9	0.2	0.0
new windows 22°C LT	1.8	0.3	0.0	0.0	0.0
extensive renovation 22°C LT	0.0	0.0	0.0	0.0	0.0
non-renovated 22°C HIGHFLOW	28.8	8.0	2.4	0.5	0.0
non-renovated 22°C Tout SHIFT	45.6	22.9	7.0	2.3	0.8
non-renovated 22 °C ODUM	36.7	16.9	2.5	0.2	0.0

T_{supply} [°C]

Figure 40. Percentage of hours during a year exceeding specific supply temperatures between 50 and 70°C.

5.1.3 General guide for temperature level selection in the transformation process

The long-term driving force to reduce the network temperature is to keep relative network heat loss low when the building heating demands are reduced due to increasingly stringent building codes. In the short and medium term, the interest in low temperature district heating includes improving heating plant thermal efficiency and increased use of locally available low-temperature heat sources. In the 4GDH concept, the selection of network temperature should follow these principles: minimizing the cost for heat production, distribution and utilization, maximizing exploitation of low-temperature waste heat or renewable heat sources, and fulfilling the requirement of hygiene and consumer thermal comfort. Constraints for temperature selection include building required minimum temperature level and the available indigenous heat sources.

The temperature level in the 4GDH system is defined as a range between 50°C-70°C for supply and 25°C-40°C for return. When a low-temperature heat source is available and economic, lower network supply/return temperature (40°C /20°C) is feasible with a thermal booster for DHW and well-designed space heating installations. To select the proper temperature level, the DH system from the heat source to the end user heating installations need to be analyzed case by case for the designated area. Flexible operational temperature can be considered to temporally boost the supply temperature during the peak heating period, while the system may operate at low-temperature for most of the year. The DH production system can be more decentralized to ease access to locally available low-temperature heat sources from industrial and commercial sectors.

Some general recommendations are given below as reference guides:

Supply temperature

- Lower supply temperature enables higher CHP plant performance, higher heat pump COP, and higher waste heat and renewable energy utilization (Dalla Rosa et.al, 2014).
- There are DH supply temperature constraints for space heating and DHW. The minimum supply temperature for space heating is limited by the building heating demand, type of heating units (radiator/floor heating) and heating installations (single string/double string, direct/indirect). The minimum supply temperature for DHW is set to avoid the Legionella risk and maintain consumer thermal comfort.
- For existing buildings, a higher supply temperature is required for the radiator system during cold winter periods, but in areas with high heat density this may be acceptable as long as high temperature production is available at acceptable cost.
- For low energy buildings with low-temperature radiators, a temperature level at 50°C /20°C can meet the building space heating demand.
- Careful design of the DHW facility is required if the DH supply temperature is around 50°C. DHW installations in single family house can be designed with such a small water volume that there is no special concern about Legionella. For multi-storey buildings, individual apartments can be equipped with flat plate heat exchangers, or else on-site temperature boosters can be used for DHW production eg electric tracing and micro heat pumps.
- DH supply temperature can be reduced by elimination of DHW tanks and circulation systems.
- For buildings with floor heating or wall heating, the supply temperature can be a few degrees above room temperature and the return temperature can be cooled down to 20°C.
- For buildings with very low heating demand, ultra-low temperature DH can be considered with on-site temperature boost through electric auxiliary heaters or micro heat pumps.

Return temperature

- Lower return temperatures lead to benefits such as lower pumping cost, lower network heat loss and higher biomass plant efficiency if flue gas condensation is used. There is no constraint for minimum return temperature.
- To stimulate users to reduce network return temperature, some DH utilities apply a rebate/extra payment for those consumers who have return temperatures lower/higher than a reference value.

- As pointed out in Section 3.2, operational errors are more critical for 4GDH due to more rigorous operational conditions. Improved operational procedures need to be implemented in consumer heating systems and substations with continuous commissioning by use of hourly reading of energy meters to reduce temperature errors and achieve a low network return temperature.
- Revise the heating installation from single string to double string, ensure that thermostatic valves are working properly and apply flow balancing to achieve a low return temperature.
- Instantaneous heat exchanger substations for DHW are more compact, incur less heat loss and lead to lower return temperatures. They are recommended for 4GDH.
- Thermal bypasses cause a high network return temperature and large relative heat loss in summer period. Solutions exist to eliminate street bypasses and building bypasses (discussed in section 5.4).

In general, the implementation of 4GDH can take place in several steps that should be considered on a case by case basis. A brief transformation guideline is shown in table 5.

Table 5. Transformation roadmap from current DH system to future low/ultra-low temperature DH system

Table 5.1. Current stage (3rd Generation)

Buildings			**DH Network (Building entrance)**	**Production**
DHW		**SH**		
High density (multi-storey building blocks)	**Low density (single family houses)**			
Existing buildings Heat exchanger/ Storage tank/ with circulation pipes Minimum supply/return temperature: 60°C-65°C /20°C -55°C	Existing buildings Storage tank /Heat exchanger No circulation pipes Minimum supply/return temperature for storage tank: 60°C/20°C For heat exchanger: 50°C/20°C	Radiator system Supply/Return temperature: 80°C -55°C /60°C-25°C	Supply Temperature: 90°C - 65°C (indirect) or 80°C-55°C (direct) Return Temperature: 70°C - 35°C (indirect) or 60°C -25°C (direct)	Conventional CHP, incineration plant, boiler

Table 5.2. 1st Step: Low return temperature

Buildings			DH Network (building entrance)	Production
DHW		SH		
High density (multi-storey building blocks)	Low density (single family houses)			
Existing buildings Circulation pipes are kept at 50°C with: - Electric tracing Micro-heat pump	Existing buildings. Bypass in heat exchanger units is made by use of bath room floor heating in summer to lower return temperature and get comfort from bypass flow	- Single string system replaced with double string -No night set-back -Thermostatic radiator valve , TRV, on each radiator -Thermostatic return temperature controller for each radiator -New electronic TRV with return temperature sensor and integrated room and return temperature controller Supply/Return temperature: 80°C-55°C /40°C-25°C. Operate the system with as low return temperature as possible	Supply Temperature: 90°C-65°C (indirect) or 80°C -55°C (direct) Return Temperature: 50°C-35°C (indirect) 40°C -25°C (direct) Bonus for low return temperature Bypass in network are minimized Low loss pipes when renovation is needed	Biomass CHP and bio-fuel boilers with flue gas condensation

Table 5.3. 2nd Step: *Low supply/return temperature*

Buildings			DH Network (building entrance)	Production
DHW		SH		
High density (multi-storey building blocks)	Low density (single family houses)			
Existing buildings and new buildings in high density areas Replace storage tank with decentral heat exchanger, flat station. With highly insulated risers from building entrance to decentral substation Supply/Return temperature: 55 °C /25 °C	Existing buildings and new buildings in low density areas Replace storage tank with decentral heat exchanger, flat station. Supply/Return temperature: 50 °C /20 °C	Supply 50°C-55°C all year round for renovated buildings. For non-renovated buildings, use higher supply temperature only during cold winter period around 60 °C -70°C Renovation measures include: - Energy saving measures in building: window, ventilation, heat recovery - Enlarge radiators in buildings where energy savings are impossible or too expensive	Supply/Return temperature 55°C /25°C all year round for renovated building, For non-renovated buildings 60°C -70°C /25°C-30°C in cold winter period. Low loss pipes when renovation is needed	Industrial and commercial waste heat, heat pump, shallow geothermal

Table 5.4. 3rd Step: Ultra-low temperature

Buildings			DH Network (building entrance)	Production
DHW		SH		
High density (multi-storey building blocks)	Low density (single family houses)			
Newer buildings and new NZEB buildings in low density areas Ultra-low temperature district heating supplemented with renewable based electrical energy DHW preheated by district heating by heat exchangers Temperature boost with auxiliary electric energy to provide DHW at comfort temperature Supply/Return temperature: 30°C-45 °C /20 °C	- Operate the SH with ultra-low temperature when possible - District heating temperature increased to needed temperature for the space heating system	Supply: 30°C-45°C Return: 20°C -25°C Ultra-low heat loss pipes used in new network	Available ultra-low temperature waste heat. For increased temperature in winter: incineration plants and RE CHP plants, Heat Pumps In transition periods return temperatures from 3GDH may be used as supply temperature	Available ultra-low temperature waste heat. For increased temperature in winter: incineration plants and RE CHP plants, Heat Pumps In transition periods return temperatures from 3GDH may be used as supply temperature

To better illustrate future temperature levels, a characteristic temperature is defined according to the type of DHW production and area heat density which is shown in Table 6. District heating systems will operate at the characteristic temperature levels in summer periods and periods with low space heating load. During cold winter periods, the temperature can be raised to meet the increased space heating demand.

Table 6. Characteristic temperature level in future DH

LTDH-version	Building DHW type	Application
65 °C /25°C	DHW tank and circulation	City central area with linear heat density above 7 MWh/m.yr
60 °C /25 °C	Central DHW heat exchanger and circulation	City central area with linear heat density above 7 MWh/m.yr
55 °C /25°C	Decentral DHW heat exchanger , indirect system with central heat exchanger from district heating system to heating system of the building	City area with linear heat density between 1-7 MWh/m.yr
50 °C /20°C	Decentral DHW heat exchanger, direct system with district heating pipes as risers in the building	low heat density area with linear heat density at 0.2 MWh/m.yr
40 °C /20°C	Decentral DHW heat exchanger and temperature booster	Area with near zero energy buildings with linear heat density 0.1 MWh/m.yr
30 °C /20 °C	Decentral DHW heat exchanger and temperature booster	Area with near zero energy buildings with linear heat density 0.1 MWh/m.yr

Further comment

There is a debate whether to apply a low supply temperature with lower delta T or a high supply temperature with higher delta T. It can be addressed as follows:

- From the heat production aspect, low-temperature district heating benefits both traditional CHP production and the use of renewable energy and heat pumps.
- From the heat distribution aspect, low-temperature district heating reduces network heat loss comparing with high temperature operation. The European Union (EU) has the target to reduce building energy use and increase the share of renewable energy. Low-temperature district heating was initially developed to maintain economic competence in low-energy building areas. In low-heat density areas, the length of service pipes accounts for 50% or more of the total length of the distribution network (Zinko et al 2008). Network heat loss reduction is therefore critical in low-heat density areas.
  In addition, to compensate for larger pipe dimensions due to reduced delta T, low-temperature district heating designs specify a higher pressure limit for the network. For example, the network design pressure in the Lystrup project in Denmark is chosen at 10 bar instead of the conventionally used 6 bar system (Dalla Rosa et al 2014).
  Furthermore, 4GDH does not exclude higher supply temperatures during cold winter periods, but does prioritise low supply temperatures for higher heating demands. Networks designed at higher delta T still allows the network to operate with a low supply temperature for a significant amount of time.

5.2 Typical thermal lengths for heat exchangers in indirect connection systems

Thermal length is also known as the number of transfer units (NTU). It is a dimensionless parameter to indicate how difficult it can be for a certain operational condition to be met for the heat exchanger. With a fixed heat exchange capacity, a longer thermal length allows a heat exchanger to operate at lower log mean temperature difference, and vice versa. A longer thermal length implies an increased heat exchanger area, which leads to an increased investment cost. Meanwhile, an increased heat transfer area cools the water more effectively thus leads to a lower DH return temperature.

For DHW supply, Euroheat & Power recommended a heat exchanger primary side inlet/outlet temperature of 60°C /25°C, and secondary side inlet/outlet temperature of 10°C /50°C. The corresponding thermal length is 3.24. For LTDH, as indicated in Section 3.1, the thermal length is 7.6 for the primary side inlet/outlet temperature at 50°C /20°C, and secondary side inlet/outlet temperature at 14°C /47°C. This new thermal length for the DHW is double that for a network operating at medium temperature level. The technology for compact heat exchangers was developed with a dimple pattern to fit the low temperature operation.

There are two types of DH connections for the SH circuit: direct and indirect connection. In a direct connection scheme, the DH water circulates directly into the building SH units. The network provides sufficient pressure head to compensate for the pressure drop for SH installations inside the building. In an indirect connection scheme, a heat exchanger separates the DH water and SH water as primary and secondary side respectively. A circulation pump is used to circulate the SH water on the secondary side. The indirect system is recommended for PN10 and higher pressure networks.

The advantage of the direct system is the system is relatively simple and there is no temperature drop between the DH and building installations. The disadvantage is that the direct system works only for networks operating at a moderate pressure level to suit the maximum static pressure requirement for the building heating installations. The pipes in the network therefore have to be designed with larger diameters. The advantage of the indirect system is that the network can be operated at high pressure. It isolates the hydraulic loop inside the building from the street pipes thus avoiding risks such as water quality contamination in street pipe and excessive water leakage inside the building due to low pressure operation. The disadvantage is that there is a temperature drop across the heat exchanger.

The temperature level in SH is not as sensitive as that in the DHW circuit as there is no hygiene issue in the closed circuit. On the other hand, thermal comfort can be satisfied by means of a smaller temperature drop across the radiator. However this subsequently incurs a higher network return temperature. There is a trade-off between investment cost increase with larger thermal length in the indirect heating system and operational cost saving through network return temperature reduction. According to the study (Thorsen et.al, 2015), increasing the thermal length by a factor 1.7 to 2.5 is recommended, assuming a 1°C lower return temperature results in 1% reduced distribution energy loss, and 12 years of reduced thermal energy loss is spent on the added thermal length.

5.3 Temperature levels in near or early 4GDH systems

5.3.1 General experiences from Danish DH systems

Current Danish DH systems are predominantly 3rd generation DH. The DH supplies existing buildings of different ages and energy use with an annual average supply/return temperature about 75°C /45°C in systems throughout the country. In larger cities with a large heating area, the DH supply temperature can be even higher, for example 85°C.

Among all the DH utilities, there are a few DH systems that have implemented low-temperature operation. The typical supply/return temperature at the buildings in such systems is about 60°C /30°C, with an increase in supply temperature during the cold winter period.

Based on the benchmark data for five DH companies with the lowest supply temperature (Dansk Fjernvarme, 2014) and an interview with their operating managers, the general consensus about the methods they have used to implement low temperature operation is as follows:

- ‘Just do it’: Gradually lowering the supply temperature and getting users with problems to improve control or performance of SH and DHW systems. In one case, there were less than 0.5% of users demanding high temperatures. It was found that the reason for these few high demands was severely underperforming DHW systems compared to typical DHW-system. By fixing such problems, big savings in production and distribution are accomplished.
- ‘Prepare it’: Analysis of possibilities for shutting by-passes in the network and carrying out a service check of user equipment may help to eliminate problems, thus reducing the operation temperature.
- ’Stick and carrots’: By introducing DH tariffs based on the return temperature, it is possible to motivate users to improve their control of the heating system and the DHW-system. A support system for users with problems is very important; hourly metering and provision of information is recommended.
- ‘Requirements’: In new buildings and when buildings and their heating systems are renovated, low temperature DH can be introduced in a cost efficient way.

Typically the different methods have been combined. Table 7 shows the collected information for the five Danish DH companies that operate at low network supply/return temperature.

Table 7. Existing Danish DH systems that operate at low-temperature. Data from Dansk Fjernvarme Statistik 2014

	Spjald DH	**Tarm DH**	**Bramminge DH**	**Malling DH**	**Middelfart DH**
Heat source	Natural gas	wood chips boiler with flue gas condensation (main source), solar, absorption heat pump, wood pellet boiler, gas and oil boilers for back up	Natural gas cogeneration	Heat from transmission network from central cogeneration plant	Transmission network – mainly from cogeneration plant and industrial waste heat
Buildings	582 (most are old buildings)	1853 (most are old buildings)	2509 (most are old buildings)	1693	5015 (most are old buildings)
SH system	Mostly direct system with radiators	Mostly direct system with radiators	Mostly direct system with radiators	Mostly direct system with radiators	Mostly direct system with radiators
DHW system	60% IHEU	DHW storage with built in heaters	IHEU (?)	Since 2008 highly efficient heat exchangers in single family houses	IHEU
Network operation temperature	65 °C /32°C for heating season, 65°C /39°C for non-heating season	65 °C /36°C all year	68°C /(?)	68 °C /38°C for heating season, 60°C /42°C for non-heating season	68°C /44°C all year
Trench length	Main pipes: 12km. Service pipes: 9km	Main pipes: 40km. Service pipes: 25km	?	Main pipes: 32km. Service pipes: 19km	Main pipes: 87km. Service pipes: 59km
Pipe ages	16 years	19 years	?	?	?

	Spjald DH	Tarm DH	Bramminge DH	Malling DH	Middelfart DH
Linear density	0.57 MWh/m	0.66 MWh/m	?	0.45 MWh/m	0.72 MWh/m
Heat delivered	12 GWh	43 GWh	50 GWh	23 GWh	105 GWh
Average annual network heat loss	202 MWh/km (26%)	140 MWh/km (17%)	20%	?	19%

Additional information related to the Danish DH systems with low-temperature operation are:

Spjald DH

- Low temperature operation has been implemented without problems.
- No penalty for high return temperatures.
- Minimum temperature for SH and DHW supply is 60°C /30°C

Tarm DH

- Low temperature operation has been implemented without complaints based on service check of installations in all buildings.
- Minimum temperature for SH and DHW supply is 60°C/30°C.

Bramminge DH

- Low temperature DH has been implemented by a combination of lowering the temperature and support to consumers with problems.
- Rebate for return temperatures below 30°C and extra payment for return temperatures higher than 30°C is 1% of variable price per 1°C to stimulate users to reduce return temperatures.
- Availability of hourly metering results for consumers has also helped to reduce their return temperatures.
- In new systems with heat exchangers, the bypass flow is shut off when a building is not being used, and opened when the light is switched on in bathroom, so that hot water production can be prepared with minimum waiting time. This reduces high return temperatures incurred by unrestricted bypass flow.

Malling DH

- Low temperature DH has been implemented without problems by proceeding with lowering the supply temperature and providing support to customers with problems.
- Extra cost of 1% per 1 °C for consumers with less than 25 °C temperature difference between supply and return.
- For new and replacement systems heat exchangers only for DHW.

Middelfart DH

- Low temperature district heating has been implemented by checking the control and performance of space heating and DHW systems in buildings. Substation equipment replaced for about 0.5% of consumers with very high return temperatures.
- Shutting bypasses in the network.
- Lowering supply temperatures in the network until users complain. Figure 41 shows the plant supply temperature and its corresponding return temperature at different measured points.
- Introducing new low temperature regime (60°C /30°C) in the technical requirements,
- Introducing motivation tariffs (next year) with a bonus/penalty on heat prices of 1% per degree if the return temperature is below/above an expected return temperature in relation to the local supply temperature – as shown below. The savings of the DH company in reduced cost of bought energy and reduced heat loss in network is about 0.5 million DKK/year per 1°C lower return temperature (equivalent to about 1% of sold energy per 1°C) .
- Technical requirements: For new and renovated systems: Supply /return temperatures for space heating 60°C /30°C at outdoor temperature of -12°C. Supply/return temperatures for DHW: 55°C /20°C.

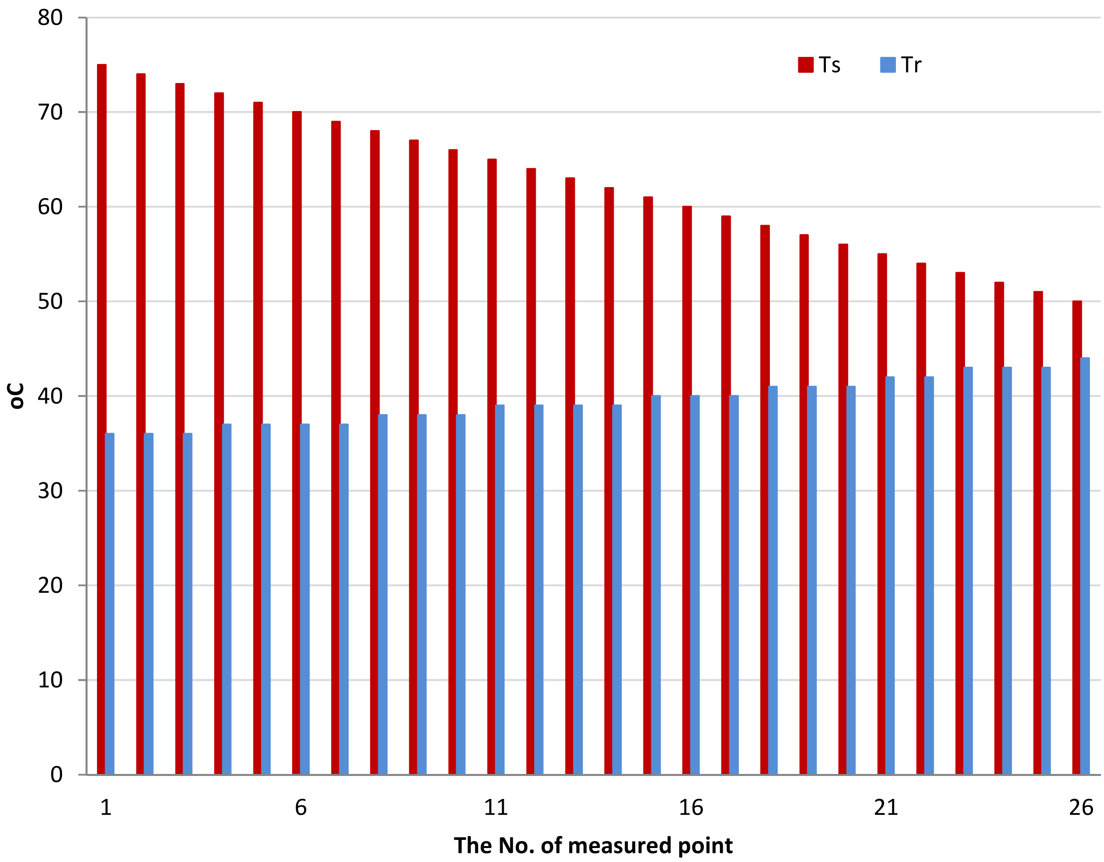


Figure 41. Measured plant supply and return temperature in the Middelfart district heating system.

Even though the DH companies are in agreement on most of the content of the technical requirements, directly opposite guidelines about DHW-systems are seen. Most are recommending the use of highly efficient IHEU DHW substations, but some state that in some areas with small network pipes, heat exchangers cannot be used due to their high peak load when hot water is used. There is a need to investigate this problem based on realistic up-to-date detailed knowledge of typical and critical use of DHW in buildings in such areas.

New solutions to minimize the problem of higher return temperatures due to bypass flow in substations with DHW heat exchangers have been applied in one of the cases. The principle is to control the bypass flow so that it is started just before it is needed. It is unclear if this principle will work if all houses in a street would not require DHW or SH for many hours at the same time as in the situation of night-time during the summer. An alternative solution could then be to use the bypass flow for comfort heating of the bathroom floor heating in summer. In this way, the energy paid for the bypass flow can be used to improve consumer comfort and provide a low DH return temperature.

In general, the experiences from the cases show that a transformation of DH at about 60°C /30°C is quite easily implemented. This may be a first step towards a future transformation to DH at about 55°C/25°C when the DHW-system in the buildings are prepared for it.

5.3.2 Case to supply low-temperature DH to existing buildings

The full scale demonstration project at Sønderby, Denmark aims to exam the feasibility and economic benefit of supplying low-temperature DH to existing building areas. The demonstrated area includes 75 single family houses which were built from 1997-1998. The previous DH network uses an old inefficient single DH pipe. The network supply temperature is about 80°C. This leads to high heat consumption of about 13 MWh /year and an annual average relative heat loss of about 41%.

As the buildings are supplied with floor heating and the DHW tanks were replaced by heat exchangers, there is a possibility to supply low-temperature DH to this area with necessary network renovation. Through the project, old inefficient pipes are replaced by low heat loss pre-insulated twin pipes. The low-temperature area is supplied mainly by return water from the main medium temperature DH network at 48°C. It covers 80% of total heat supply. This return water mixes with supply water at the shunt in order to raise the water temperature up to 55°C to supply the designated area. In summer, return temperature from the main network becomes higher and thus can provide 100% of the heating demand. The design supply temperature to the consumer is 52°C with 25°C cooling by consumers. The maximum pressure level is 10 bar with differential pressure at the critical user at 0.3bar.

The annual network heat loss is reduced from 41% to 13-14%. The significant heat loss reduction is mainly due to the reduced network temperature, improved pipe insulation, reduced dimension of pipes by using high network pressure. During operation, it was found that network return temperature was close to 40°C. This high network return temperature is due to a large bypass flow rate in some incorrectly set control valves. Another reason is due to consumers who forgot to close valves for the heating system during the summer season. This issue of heating system valves left open in summer should be avoided in future by installing return temperature limiters on the SHheat exchangers.

The full-scale demonstration project has shown existing buildings with floor heating can be supplied with low DH temperature without building renovation. A great heat saving potential can be achieved through low-temperature DH supply.

Figure 42. Area with full scale demonstration of LTDH at Sønderby, Copenhagen

5.3.3 Case for ultra-low temperature DH

Bjerringbro DH in Jutland, Denmark developed an ultra-low temperature DH network to supply residential buildings. The heat source is industrial excess heat from a local pump plant, recovered by a heat pump for DH use. The buildings are single family houses built in the 1970-80s.

The ultra-low temperature DH network supplies heat at 46°C when the outdoor temperature is above 5°C. The supply temperature increases by 1°C for every 1°C decrease of outdoor temperature when the outdoor temperature is lower than 5°C. A total 21 local households are connected to the DH network. All the substations installed local supplementary heating devices in order to produce DHW according to the set-point temperature. The building substations include five types as shown in Figure 43 (Yang et.al, 2016).

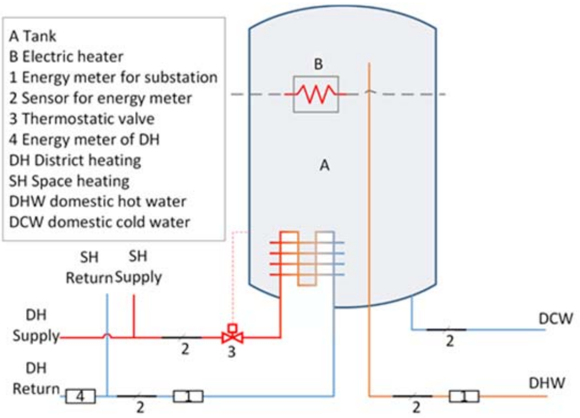
- Figure 43 a is for a DHW substation with a conventional storage tank. The storage tank volume is 160 L. An electric heater with 3kW capacity is located on the upper part of the tank. DHW is preheated by the DH water and can be heated up to 60°C by the electric heater to prevent Legionella.

- Figure 43 b is for a DHW substation with DH storage tank. The storage tank on the secondary side is moved to the primary side. A heat exchanger separates the storage tank from the water tapping. In this way, a lower storage tank temperature is allowed. The tank outlet temperature is controlled at 50°C-55°C and the hot water is produced instantaneously with the heat exchanger.
- Figure 43 c is for a DHW substation with a storage tank boosted by a micro heat pump. The DH supply water is split into two parts and feeds into the heat pump condenser and evaporator separately. The heat pump operates to recharge the tank when the tank temperature drops below 55°C.
- Figure 43 d is for a DHW substation with an instantaneous heat exchanger. The heat exchanger exchanges heat with the DH supply water. The DHW for kitchen use is heated up to 50°C with an auxiliary electric heater. The capacity of the auxiliary electric heater is 11kW. The proper temperature before tapping can be controlled with mixing of cold water.
- Figure 43 e has a similar DHW layout as in Figure 43 d. The difference is that DHW for both kitchen and shower are heated up to 50°C by the auxiliary electric heater. The capacity of the auxiliary electric heater is 18kW.

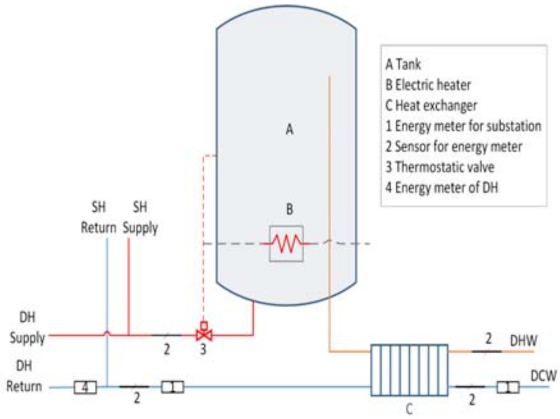
The heat supplied by DH and the total energy consumption which includes both heat and electricity are measured. The results showed that substations with storage tanks and heat pumps have relatively high electricity consumption, which leads to higher integrated costs considering both heat and electricity for DHW production. The substations with in-line electric heaters have relatively low electricity usage because very little heat is lost due to the instantaneous DHW production. Accordingly, the substations with in-line electric heaters would have the lowest energy cost for DHW production.

The instantaneous production of DHW leads to a high peak load with large variation compared with the application of storage tanks. In ULTDH, the electricity peak loads should be considered together with the features of district heating supply.

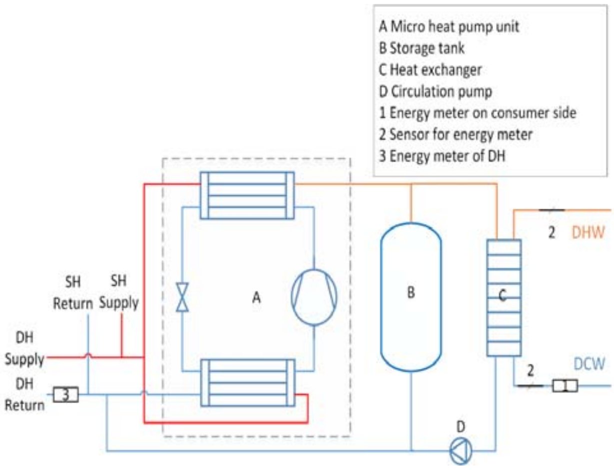
The results also show the return temperature from DHW production can influence back to the DH network, and the impact can be significant in summer.



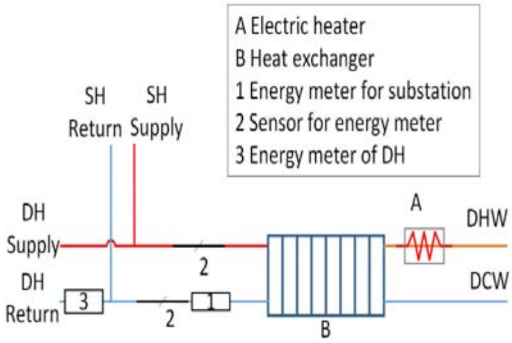
a. DHW substation with conventional storage tank



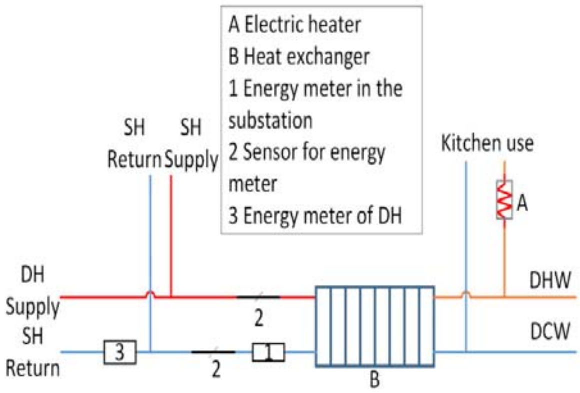
b. DHW substation with DH storage tank



c. DHW substation with a storage tank boosted by a micro heat pump



d. DHW substation in instantaneous heat exchanger with auxiliary electric heater only for kitchen



e. DHW substation in instantaneous heat exchanger with auxiliary electric heater

Figure 43. DHW substations in Bjerringbro DH system.

5.4 Strategies for heat distribution with no bypass

In the summer, the required water flow rate in the DH network is reduced significantly as a result of greatly reduced consumer heating load. Due to heat loss to the ground, a small flow rate will cause the water to undergo excessive temperature drop while in transit from the heating plant to consumers. In order to keep the DH supply water warm, thermal bypasses are installed at the end of the street pipe (street bypass) and the end of the branch pipe in the heat exchanger system that connects to the DHW substation (service pipe bypass). Through the bypass valves, warm water circulates through the supply pipe and flows back to the return pipe, without releasing heat for heat demands.

The aim in using a bypass is to keep the DHW substation warm during the low SH load season and non DHW draw-off period (which is significantly longer than the draw-off period). In this way, the DHW substation is able to warm up cold water in a timely manner and produce DHW without delay, thus satisfying consumer demands. However, as bypass water is a short-cut to the return line, the network return temperature becomes high which incurs higher network heat loss and lower biomass heating plant efficiency if flue gas condensation is used.

The bypass flow rate is determined by the bypass set-point temperature. The bypass set-point temperature relates to DHW thermal comfort. DHW comfort is defined both in terms of temperature level and the waiting time. In general, the DHW comfort temperature is lower than the temperature required for the hygiene issue. In Denmark, the DHW temperature at the tapping point in the kitchen is 45°C and at other tapping points is 40°C. The waiting time is defined as the time period from the start of the tapping until the desired hot water temperature reaches the tapping point. There are multiple factors that influence the waiting time: the length, thermal capacity and insulation of distribution pipes, the thermal capacity of the heat exchanger, and the set-point temperature of the thermal bypass.

In general, there are several principles to consider in order to eliminate the service pipe bypass. The 1st principle is minimum cooling. A triple pipe is considered in the service pipe for the minimum cooling principle. This comprises two supply pipes and one return pipe, co-insulated in one casing. One of the supply pipes is used as a re-circulation pipe in the minimum cooling concept. Instead of by-passing the DH supply water to the return line, the supply water is directed to the re-circulation pipe and flows back to the street supply pipe. With this strategy, the temperature cooling in this circulation loop should be kept as small as possible. A circulation pump is used to compensate the pressure loss in this local hydraulic loop.

The 2nd principle is achieving maximum cooling wherein the bypass water flows through additional heat demand(s) before it goes back to the return line. Such additional heat demand can be bathroom floor heating etc.

The 3rd principle is based on provision of an on-site thermal boost. An auxiliary heater is provided for consumers located at the edge of the DH network. The supply water is cooled freely without the aid of bypass. Upon reaching the building, the low-temperature DH supply water is re-heated by means of a small heat pump. In this way, both street bypass and service pipe are eliminated.

The 4th solution is to eliminate the service pipe bypass with on-site auxiliary heating units, like a Quooker. A Quooker is a small vacuum insulated electric heated tank that can produce boiling water. As there is no thermal bypass, during the non-draw off period, the DH water is cooled due to heat loss to the ground. At the beginning of draw-off, the DH supply water to the substation is cold water that cannot be used to produce DHW. The time required to expel this cold water unacceptable from the thermal comfort point of view. Quooker provides hot water that can be mixed with the cold DH water at the beginning of draw-off. In this way, DHW at a comfortable temperature is produced with only a short waiting time.

One solution to eliminate street pipe bypasses is to connect the DH pipes from different streets into a looped network. The DH supply water from the heating plant passes through all streets and then returns back to the plant. In this way, all street pipes are kept warm whereas the return line is kept cold.

In addition to eliminating the bypasses, in the 4GDH concept efforts are made to eliminate the DHW circulation pipes in buildings. In single family houses, circulation pipes should not be necessary if small diameter pipes are used between the heat exchanger and the tapping point. For multi-storey buildings, the circulation pipe is part of the riser system. Circulation pipes increase the total water volume in the DHW system thus increasing the risk of Legionella when the DH supply temperature is reduced. Circulation pipes also lead to large distribution heat losses.

In multi-storey buildings, one of the solutions to eliminate circulation pipes is to use a flat station in each single apartment. Other concepts to eliminate circulation heat loss include in-line circulation and electric tracing (Yang et al, 2016). In-line circulation has the circulation pipe embedded inside the supply riser, thus reducing the circulation heat loss, with a stainless steel external supply pipe and a PEX internal circulation pipe.

Electric tracing uses an electrical cable in thermal contact with the entire length of the external surface of the supply pipe. The heat loss in the supply pipe is compensated with electric power, thus the circulation pipe in the system can be eliminated.

5.5 Conclusions about future temperature levels

This chapter proposed stepwise transformation from 2nd or 3rd generation DH to 4th generation low temperature DH –see table 8. The major conclusions drawn from this chapter are:

- The temperature level in the 4GDH system is defined as a range between 50°C - 55^{o}C in summer to 60 °C -70°C in winter for supply temperature, and 25°C -30°C in summer to 40°C in winter for return temperature (Olsen et al 2014). With temperature booster, lower supply temperature down to 30°C-40°C is possible.
- The transformation roadmap is stepwise. In the first step the return temperature is reduced to 25°C when possible by better control of space heating systems. Error-free consumer heating systems are critical to ensure low network return temperature. In the second step the supply temperature is reduced to 55°C when possible. The third step is using ’cold’ DH with temperature boosters.
- The higher temperature limit in the supply temperature definition is required for existing buildings which demand large space heating consumption and are heated with radiators. However, this high supply temperature is required only in a short cold winter period and such buildings can be supplied with low-temperature at most of the time.
- DHW can be supplied with low-temperature at 50°C by use of local DHW substation. Alternatively various Legionella treatment solutions are available to assist the low temperature operation of conventional DHW tank and circulation systems. Instantaneous heat exchanger substation is recommended for 4GDH.
- For DHW substation, a thermal length between 6 and 8 is recommended. In in-direct heating system, increase of thermal length by a factor of 1.7 to 2.5 is recommended when considering the trade-off between energy saving and investment cost increase.

Bypass causes higher network heat loss and pumping energy due to redundant network flow. There are several principles as minimum cooling, maximum cooling and on-site thermal boost that can eliminate the bypass, while maintain the normal consumer heating supply.

1 *Table 8. Initiatives and ranked (1-3, with 1 as high and 3 as low) main initiators in the transformation process*

	Main actors Initiatives	Energy planners	Decnsion makers	Heat and power producers	District heating utilities	Equipment prodcuers	Consultants	Service providers	Consumers/ Building owners
1st Step Transformation	Introduce return temperature dependent DH tariff	3	2	1	1				
	Identify malfunctioning substations and remove errors				1	1		1	2
	Develop and install new thermostatic radiator valve with return temperature controller				1	1		1	2
	Provide service to educate customers how to properly use the heating system				1			1	2
	Replace single string system with double string, reduce bypass and circulation losses in buildings		1		2	3		1	2
	Operate the network with optimal temperatures with respect to lowering the return temperature to 25°C	3		2	1				

	Eliminate the use of thermal bypass in the network			3	1	2	2	1	1
2nd Step Transformation	Reduce energy use and upgrade heating system when renovation of the building is needed				3		1	1	2
	Replace central DHW storage tank with decentral heat exchanger				2		1	1	2
	Exploit low temperature renewable and waste heat	1	1		1	3	2		
	Operate the network with optimal temperatures with respect to lowering the supply temperature to 55°C			1	1			2	2

- Decision makers: building regulation developers, etc
- Service providers: Companies improving the operation HVAC systems of buildings

6 Concurrent operation of different generations

This chapter focuses on the possible methods to connect new 4GDH areas within existing systems beyond that was identified at previous generation shifts as reported in Chapter 2.

6.1 New 4GDH parts in existing systems

The meaning of concurrent operation is the strategies to apply in order to connect and operate new 4GDH parts in existing district heating systems designed and operated according to the 2GDH and 3GDH principles. These strategies are needed since the new principles of 4GDH will first be applied in newly developed areas with mainly residential buildings demanding lower temperatures. Existing buildings will still use higher temperatures and will be served by conventional 2GDH or 3GDH technology for some decades. But also these areas will be refurbished in the future and will be able to use 4GDH technology. Concurrent operation is then about the coexistence of 2GDH, 3GDH, and 4GDH technologies in the same district heating system.

The main purpose with these concurrent operation strategies is to counteract the major temperature efficiency drawback in a district heating system: It is that the customer with the highest temperature demand sets the level of the supply temperature in the whole heat distribution network.

Some of these strategies can be based on current experiences of concurrent operation. Hereby, the next section will provide a short overview of some of these experiences.

6.2 Current experiences of concurrent operation

Current experiences of concurrent operation include multi-level temperature systems, use of primary and secondary networks, supply-to-supply connections, and return-to-return connections. The two latter connections are compliments to the ordinary supply-to-return connection for heat deliveries. The fourth connection principle of return-to-supply connection is only used when customers provide heat to the network (prosumers).

6.2.1 Multi-level temperature systems

SEMHACH, a district heating provider in the southern suburbs of Paris, operates a district heating system with five different temperatures for the cities of Cheville-Larue and L'Hay Les Roses with total heat deliveries of about 600 TJ per year. The temperature levels and the corresponding pipes are defined as Liaison (supply), Haute (high), Moyenne (medium), Basse (low), and Tres basse (very low) (Semhach 2002). The supply temperature pipes interconnect the major heat supply plants. Customers are connected between suitable temperature levels depending on the customer temperature demands. One customer can be connected between the high and medium temperatures, while another can be connected between the medium and low temperature pipes.

All temperatures are not available everywhere in the network, but are supplied on demand and availability. The system has 65 km of pipes for the 23 km of trench length, indicating that 2.8 parallel pipes are used in average (Semhach 2011). The most common connections are still between the high and medium temperature levels in areas with ordinary two-pipe networks.

The main purpose with this cascading multi-level temperature system is to increase the utilisation of several geothermal wells used for base load operation. Geothermal heat constituted 59 percent of the heat supply in 2014. By cascading the heat use, a lower aggregated return temperature is obtained, making it possible to extract more geothermal heat from the existing boreholes.

Some parts of the Berlin district heating system have a three-pipe system consisting of two supply pipes and one return pipe (Frederiksen et al 2013). One supply pipe is used for space heating applications, while the other supply pipe provides heat for preparation of domestic water. The benefit with this configuration is that the supply temperature for space heating is varied according to the seasonal heat and temperature demand, while the other supply temperature is kept constant in order to manage only the temperature demand for generating DHW. This basic principle was introduced in the early days of the Berlin district heating system in the 1920s.

The use of multiple distribution pipes with different temperatures is also the main theme for the LowExTra project, supported by the German Federal Ministry for Economic Affairs and Energy. The project description (EnEff Stadt 2016c) mentions the suggested temperature levels of 15, 30, 45 and 60 °C to be explored by the project.

6.2.2 Division between primary and secondary networks

Vienna has divided its heat distribution network into one primary network and many secondary networks. The primary network has a high temperature level corresponding to 2GDH technology and contains the main transmission pipes, but some customers are also connected to this part of the network. Several hundred secondary networks are fed by heat from the primary network through central substations. These secondary networks are designed according to the 3GDH principles and consisted of 53 percent of the total trench length in 2013 (Wiener Stadtwerke 2016).

The Copenhagen metropolitan area has a regional district heating system based on primary and secondary networks (Frederiksen et al 2013). The primary network consists of transmission pipes and is operated by two transmission companies (CTR and VEKS). It operates according to 2GDH temperature principles and delivers heat to secondary networks, based on 3GDH technology. The heat is transferred by large central substations to each secondary network, one for each municipality in the region. The heat exchangers in these central substations have long thermal lengths.

Similar division of primary and secondary networks is also often applied in Russia and China, since it was a typical district heating standard in the former USSR. Riga in Latvia and some other former USSR district heating systems have successfully managed to rebuild such a divided network design into one integrated network by removing all central substations during less than ten years. Hereby, they have succeeded to implement the transformation from concurrent operation of the 2GDH and 3GDH technologies to integrated networks with typical 3GDH performance indicators.

6.2.3 Supply-to-supply connections

Supply-to-supply connections are using a flow from the supply pipe that is also returned to the supply pipe. They are applied when the customer substation generates a return temperature just below the supply temperature. This very high return temperature is not suitable for the ordinary return pipe, since it will increase the network temperature level.

Bromölla district heating system (BEVAB 2016) in Sweden applies a supply-to supply connection for major industry (Ifö Sanitär). Heat is recovered from a paper and pulp plant at a temperature of about 110-125 °C. This supply flow is first delivered to the industry that reduce the supply temperature to 65-90 °C, which is a suitable supply temperature for the local district heating system in Bromölla, providing a final return temperature of 45 °C. Hereby, the return temperature from the industry becomes the supply temperature for the buildings in the urban area.

Supply-to-supply connections are also suitable for heat deliveries to local absorption chillers. They often need large supply flows and generate high return temperatures. By using supply-to-supply connections, the return pipes will not be polluted by high temperature return flows.

However, supply-to-supply connections cannot be applied everywhere in the distribution networks, since the supply flow must be rather high at the connecting point. Hence, this method can only be applied close to major transmission or distribution pipes. It cannot be applied in the network peripheries, where supply flows are low. A local supply-to-supply connection requires also a local pump for creating the flow through the substation, since the available differential pressure from the feeding supply pipe is zero.

6.2.4 Return-to-return connections

Return-to-return connections are using a flow from the return pipe that is also returned to the return pipe. They are applied when the customer substation requires a supply temperature close to the actual return temperature in the network. This kind of connection is suitable for customers having low temperature demands, as low energy buildings. Other examples of low temperature demands are ground heating, underfloor heating, swimming pools, preheating of ventilation air etc.

The same hydraulic conditions apply for return-to-return connections as for supply-to-supply connections. They can only be performed close to large pipes having large flows and a special circulation pump is also required at each connection point.

6.3 Conclusion about concurrent operation

The main conclusion about concurrent operation is: It should be possible to elaborate effective strategies for concurrent operation to facilitate parallel use of current 2GDH/3GDH systems together with new 4GDH parts with respect to operational, technical, and general conditions. The demand for concurrent operation will occur since 4GDH system parts will be introduced before the current system parts can apply the new 4GDH technology. Some years will be required to lower the customer temperature demands in existing buildings by energy efficiency measures.

7 Conclusions

The conclusions provided consist of the answers to the seven research questions put forward in the introduction:

1 **What experiences are available from previous shifts of technology generations for district heating**?

Answer: Hot water DH systems (2GDH and following generations) offer a lot of well-known advantages in terms of economic and ecological performance compared to those DH systems of the 1GDH operated with steam as heat carrier. Besides there are new heat generation options and system performance issues that are identified as driving forces for DH generation and technology shifts.

The shift from any fossil to renewable or waste heat sources makes DH more attractive to local authorities as an important component in urban energy planning. In most cases, these advantages lead the owner of the DH system to update from 1GDH to any higher generation. With respect to the supply tasks and technical systems at the client site normally transformation to 2GDH is done as a first step. This dedicated shift from steam to water is realized either by installing new hot water DH systems indirectly connected to existing steam systems or by substituting existing steam systems by new water systems. While adding hot water circuits to a steam back-bone network can be realized quite easily without significant impact on the steam system the changeover from steam to water has to be prepared and organized very carefully to keep the heat supply in operation thus satisfying clients.

Further transformation to low temperature DH (3GDH or 4GDH) can be realized in similar ways: often the return temperature of the 2GDH systems are used as the supply line for a low temperature DH. In addition, temperatures of the 2GDH will be lowered step by step but asking for concerted actions with the client to avoid under-supply. That is why further reduction of DH temperature levels is according to improved energy performance of buildings.

Building owners and operators do ask for heat from sustainable sources. Low primary energy factors (PEF) of DH systems are very welcome to fulfill national building codes. Integration of renewable and sustainable heat sources into DH systems will help to keep PEF low. The characteristics of these heat sources (e.g. low temperature and fluctuations) do not ask for low DH temperatures only but new technologies to handle and manage these heat sources are required. Advice has to be offered to building owners, architects and engineers on how to deal with process heat, DHW generation and absorption chillers when DH temperatures decrease following the transformation road map.

2 What are the current temperature levels and the corresponding hydraulic situations used in district heating systems?

Answer: Temperatures in existing DH systems differ across a wide range. There are large differences among DH systems in supply temperatures as well as in temperature differences. In general, supply temperatures are at least 70°C, but also maximum temperatures up to 130°C can be observed depending on the design situation.

Current temperature levels in current 3GDH systems are about 50-60 °C higher than ambient temperatures. These temperatures are elevated by about 10-15 °C compared to expected temperature levels because of temperature errors in distribution networks, customer substations, and customer heating systems. These errors increase network return temperatures, also requiring higher supply temperatures, since the current hydraulic systems require a certain difference between supply and return temperatures. Use of indirect connections with heat exchangers in substations also contributes to higher temperature levels.

3 What are the possible solutions to reduce the current temperature levels used in district heating systems to a level close to the temperatures needed in the buildings?

Answer: Three main strategies can be identified from the analysis of current temperature levels. First, all identified temperature errors in distribution networks, customer substations, and customer heating systems in current 2GDH and 3GDH systems should be eliminated. Second, longer thermal lengths should be implemented in substation heat exchangers. Third, customer temperature demands in both new and existing buildings should be reduced.

4 What are the current temperature levels used in customer heating systems?

Answer: It appears from the results of the survey that, although overall system flow and return temperatures may be known, more detailed information concerning customer radiator temperatures is not widely known. However, in order to operate a low temperature district heating system in an optimal way, this information is vital. Information about radiator temperatures can benefit *all* district heating systems, and the behavior of the radiators (or other heat emitters) is fundamental to successful transition from higher to lower temperature district heating, for example from 1 or 2GDH to 3GDH or from 3GDH to 4GDH.

In the context of this research project, it was possible only to carry out a survey to assemble data. It was not possible to undertake the task of physically collecting such data. Consequently, the over-riding recommendation from this part of the study is for a research project focusing on collection of temperature data at the radiator (and other heat emitter) level. The research team believes that this can be a further significant step towards more efficient overall district heating performance and a key enabler in the successful transformation of existing district heating systems.

The research carried out in Switzerland revealed the only source of in-depth information of this kind. Here, the operational supply temperatures for SH is generally between 40 and 70°C. In new buildings equipped with underfloor heating systems, the operational supply temperature is typically between 25 and 35°C. The temperatures required for DHW preparation is mainly driven by the prevention of legionella generation (50-60°C is internationally considered as usual). DHW production often implies higher supply and/or return temperatures than SH because of legionella risks. Therefore the DHW production profile may influence the required supply/return temperatures of low temperature district heating networks.

5 What are the possible solutions to reduce the current temperature levels used in customer heating systems while still satisfying heat demand with a correctly working heating system?

Answer: Customer temperature levels can be decreased by optimizing the heat distribution in buildings; examples include envelope refurbishment to lower heat demand; supply temperature management; hydraulic balancing; variable-speed pumps; functional thermostatic valves). When carrying out envelope refurbishment, radiator sizes should be kept the same as from before refurbishment. In new buildings, the use of small radiators should be avoided. Instantaneous production for DHW (without storage thus at lower temperature) is preferred, implying longer thermal lengths in substation heat exchangers.

Hydraulic schemes in substations should be conceived and adopted in order to achieve the lowest possible return temperature.

6 What temperature levels can be achieved in future district heating and customer heating systems and what are the corresponding low temperature heat sources?

Answer: The transformation from current DH systems to future low/ultra-low temperature DH systems can take place in several steps, depending on the type of DHW production units, the line heat density, and economic benefits influenced by the supply/return temperature level when considering the entire chain of heat production, distribution and consumption. Future DH temperature levels can follow the recommended characteristic temperatures as defined in Table 6 in Chapter 5.

In the case of transition from fossil fuel based CHP to biomass based CHP, the 1st step of DH water temperature reduction can take place for the return temperature thanks to improved control of radiators. This enables heat recovery from flue gas condensation. The impetus to achieve lower return temperature at the consumer ends can be stimulated by means of a temperature dependent tariff.

DH utilities need to coordinate with building owners to identify malfunctioning substations and eliminate the temperature errors. Meanwhile, they need to provide a service to the building owners to educate them about how to use their heating system properly. The operation of the DH distribution net should be optimized with respect to lowering the return temperature to 25°C by eliminating by-passes and by implementing an optimal supply temperature.

When low temperature heat sources are gaining precedence the 2nd step of DH water temperature reduction can take place by a reduction in the supply temperature to levels of 55°C needed for the DHW-production. For high density areas or buildings where energy savings are impossible or too expensive, a higher supply temperature may be used to secure thermal comfort in the cold winter period.

For low density DH areas with buildings that are heated by low temperature heating systems like floor heating, with heat production based on heat pumps, waste heat and renewable heat, supply temperatures as low as 35°C may be introduced to improve the efficiency of the network.. This low supply temperature can be used for SH and preheating of DHW but supplementary electrical based heating will be needed for delivering DHW at comfort temperatures of 40°C-45°C.

The implementation of the 3rd transformation step does not necessarily have to wait for the other two steps as it may take place in other areas. It engages different stakeholders from both heating and electricity suppliers due to the on-site electric boosters. It might demand new business models as currently free-of-charge waste energy can become another commodity in a future low energy society.

Reduced network supply temperatures benefit conventional CHP performance (Dalla Rosa et.al, 2014). Low supply temperature also encourages decision makers to exploit local low temperature renewable energy sources and waste heat. Such heat sources can be industrial and commercial waste heat, heat pumps, and shallow geothermal.

7 What are the operational, technical and general conditions for concurrent operation of current and future parts of a district heating system with respect to their different temperature levels?

Answer: It should be possible to elaborate effective strategies for concurrent operation to facilitate parallel use of current 2GDH/3GDH systems together with new 4GDH parts with respect to operational, technical, and general conditions. The demand for concurrent operation will occur since new 4GDH system parts will be introduced before the current system parts can apply the new 4GDH technology. Some years will be required to lower the customer temperature demands in existing buildings by means of energy efficiency measures.

8 Project recommendations

The conclusions from this project are here translated to a transformation roadmap describing how to get from high to low temperature district heating systems. The roadmap consists of the following recommendations including some associated technical and legislative issues:

A. Recommendations from experiences gained from earlier shifts of technology generations

<u>DH operators</u>

The technology shift and transformation from an existing DH system operated with either steam or water at high temperatures to a DH system operated at lower temperatures can be done in two very general ways:

1) Setting up a DH system in parallel that takes step by step the supply task of the existing system. This approach has often been realized when shifting from 1GDH, i.e. substituting steam by hot water but detailed planning and carefully arranged construction work is needed to avoid interruption to heat supply. In some cases existing pipes can be re-used after the steam-to-water transformation thus avoiding construction work. In addition, a new and separate low temperature DH system not linked to an existing high temperature DH network can be established from scratch. and will contribute to the transformation within the DH operators portfolio.

2) Connecting a new DH system to an existing DH system in series. This is often done when a low temperature secondary circuit is connected to the high temperature primary circuit. This connection can be realized in substations either directly or indirectly (if steam is the primary heat carrier it must be an indirect connection). If the primary return temperature is sufficient for the supply task of the low temperature secondary circuit it is recommended to use this to further cool the primary return temperature. Primary supply flow can be used as back-up or to match peak loads. The new low temperature DH system which is added should not limit options to further reduce flow temperatures in the existing hot temperature DH system.

Local authorities

The request for sustainable and low emission heat supply in urban areas leads to rethinking the existing heat generation technologies. In particular, low temperature DH in 3GDH or 4GDH systems is able to provide environmentally friendly heat from renewable or waste heat sources thus helping local authorities to meet their local climate protection policies. Due to the fact that the transformation of an existing DH system is a long-term project, local authorities and DH operator/owners have to work together when shifting DH generations and orchestrating transformation steps. Exemplarily infrastructure measures could be coordinated to allow the DH company to easily get access to the underground piping system without extra scarifying the road surface. Beside also permissions to get access to renewable energy sources to be integrated in the low temperature DH networks could be offered by the local authority without extra constraints.

B. Recommendations of methods and programs for getting lower temperature levels in existing district heating systems

- Identify current temperature errors in distribution networks, customer substations, and customer heating systems and eliminate them.
- Expand the possibilities to use continuous commissioning for monitoring customer substations in order to quickly identify new temperature errors.

C. Recommendations for getting lower temperature demands in customer heating systems

- It seems that the operating status of customer heating systems is an often neglected part of DH systems. Yet there can be much to gain by making sure that these systems are carefully set-up; existing older systems can often be significantly improved, while new DH systems serving new-build developments can operate efficiently and economically only if every part of the system is optimised, including the customers' radiators.
- Where investigations have been carried out the potential for improvement has been clear; it is therefore strongly recommended that more attention be paid to observing the operating conditions of customer heating systems. Specific examples of poor set-up in existing DH systems observed anecdotally in the UK

revealed valves left fully open, even sometimes wrongly installed, and pumps running flat out.

- Better understanding of customers' heating systems is an intrinsic requirement for ensuring successful future heat networks based on the principles of 4GDH systems. It is therefore recommended that further research examining these next generation systems should include detailed monitoring of internals. This will not only help to ensure the best operating regimes, but is also a fundamental aspect of optimal overall system design and consequent consideration of the need for improved component design.

- Specific recommendations arising from the monitoring programme that has already been carried out in Switzerland include:

    - Invite strong involvement from the HVAC community in order to serve future low temperature demands in an optimal way.

    - Keep the current standard radiator sizes in existing buildings and avoid the use of small radiators in new buildings.

    - Advocate using floor heating in new buildings (95% in Denmark).

    - Optimise the heat distribution in buildings (envelope refurbishment, hydraulic balancing, variable-speed pumps, properly functioning thermostatic valves).

    - There are several options for obtaining low temperature demands: reducing heat demand by means of energy saving measures at the building level (insulation, air tightness); increasing heat transfer area (heat exchangers, radiators, floor heating systems), adding local reheat (direct electrical or heat pump). The integration of renewables (e.g. solar thermal) will not have an immediate impact on lower temperature demands as long as renewables do not 100% cover heat demand and DH back-up is needed. Hereby, small solar thermal systems can be connected by return-to-return connections.

D. Recommendations for temperature levels in future district heating systems

- Pipes kept as a container for the heat carrier

- Water kept as heat carrier

- Connection of new buildings at the construction stage is half the cost compared to the cost for connection of existing buildings
- Use no storage tanks in substations
- Use longer thermal lengths in substation heat exchangers
- No use of traditional by-pass valves in distribution networks
- If there are separate operators (for DH network and for the buildings), incentives (bonus/malus) or binding contracts (with penalties) can help in achieving low return temperatures.

A characteristic temperature level is recommended for future DH temperature levels. Depending on the type of DHW substation and the area heat density, DH systems will operate at the characteristic temperature level in summer time periods and the periods with low space heating load. During cold winter periods, the temperature can be raised to meet the increased SH demand.

Specifically, the supply temperature of DH to buildings in future can be lowered to levels of 65°C, 50°C or 35°C depending on:

- temperature required for DHW heating and SH in different types of buildings and heating systems
- optimal reduction of heat loss in networks depending on specific heat density
- optimal cost reduction in production of heat depends on the specific type of production: renewable energy and waste heat.

For supply temperatures of 35°C, electrically based temperature boosting will be used for heating DHW.

The DH return temperature will in future be lowered to about 20-25°C as that is possible if systems for DHW and SH are well designed and controlled.

E. Recommendations for concurrent operation of 3GDH and 4GDH elements in the same DH systems.

- Each DH system should elaborate a suitable strategy for introducing new 4GDH parts in existing 2GDH and 3GDH systems.

- 2GDH and 3GDH pipes and substations can then be kept until the customer heating systems have been refurbished for low temperature operation.

Concluding words

The main benefit from this project should be a clearer overview about the temperature level issue for district heating systems, which will increase the future competitiveness of district heating. We also believe that the results will be useful within a wide timeframe from immediate use (< 5 years), to short-term use (5 to 15 years) and long-term use (>15 years).

We anticipate that the methods elaborated and the results gained from this project will be applicable and transferable to many other countries in the following manner:

- Applicable to countries with steam systems wishing to migrate to hot water (and may be able to skip intermediate generations of technologies).
- Applicable to countries with mature 3GDH markets: because they are now looking for the best possible efficiencies in pursuit of low carbon communities and gradually 'decarbonizing thermal grids'.
- Applicable to emerging markets because they may be able to skip earlier technology generations and go for the latest best available technology.

Many European heat users are currently taking decisions of not using district heating in the future. They consider only the current district heating technology when they are doing their assessment of the future competitiveness of district heating. They are not aware of the future district heating technology, since the district heating providers do not inform them about the future possibilities for district heating. The district heating industry and its advocates must take this information responsibility. Otherwise, they will not keep their customers in the future.

Bibliography

AGFW 2013 — T*ransformationsstrategien von fossiler zentraler Fernwärmeversorgung zu Netzen mit höheren Anteilen erneuerbarer Energien*; Forschung und Entwicklung Heft 24, www.agfw.de, 2013

AGFW 2016 — Liste der f_P-Bescheinigungen nach FW309-1 https://www.agfw.de/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/agfw/content/linkes_menue/erzeugung/Energetische_Bewertung/EnEV_und_Fernwaerme/Liste_der_fP-Bescheinigungen_nach_FW_309-1.pdf&t=1466164366&hash=8b55b15580916b22f2f0a70a6a8def6ebbd5471b

Boverket 2010 — Boverket (2010): *Energi i bebyggelsen – tekniska egenskaper och beräkningar – resultat från projektet BETSI,* Sweden http://cisbo.dk/sites/default/files/BETSI-Energi-i-bebyggelsen.pdf

Brand et al 2013 — Brand, M., Svendsen, S., *Renewable-based low-temperature district heating for existing buildings in various stages of refurbishment*, Energy 62 (2013) 311-319

BEVAB 2016 — Bromölla Energi & Vatten, *Så fungerar fjärrvärmen* (How our district heating system works). Website: http://www.bevab.se/fjarrvarme/fungerar.html

British Standards 1977 — BS 3528, Specification for convection type space heaters operating with steam or hot water, British Standards Institution,1977

CEN 2014 — prEN 4-4-5 *Heating systems and water based cooling systems in buildings - Method for calculation of system energy requirements and system efficiencies - Part 4-5: District heating and cooling*; CEN/TC 228, October 2014

Christiansen et al 2012 — Christiansen, CH; Dalla Rosa, A.; Brand, Marek; Kaarup Olsen, P.; Thorsen, JE (2012): *Results and experiences from*

	a 2-year study with measurements on a new low-temperature district heating system for low-energy buildings. 13th International Symposium on District Heating and Cooling, Copenhagen, Denmark
ConEdison 2012	ConEdison (2012), *Steam Long Range Plan 2011-2031*. New York.
ConEdison 2013	*Con Edison Steam Best Practices Report. Steam Use Efficiency & Demand Reduction*, October 2013
COPH 2015a	http://www.districtenergypartnership.com/da-DK/CASES/CASES-COPENHAGEN/OPTIMISING-ENERGY-CARRIERS.aspx
COPH 2015b	http://www.veks.dk/en/focus/district-heating-in-copenhagen
Dalla Rosa et al 2014	Dalla Rosa, A., Li, H., Svendsen, S., Werner, S., Persson, U., Rühling, K., Felsmann, C., Crane, M., Burzynski, R., Bevilaacgua, C. (2014), *Toward 4th Generation District Heating: Experience and Potential of Low-Temperature District Heating.* Annex X final report no.3, IEA implementing agreement on District Heating. http://www.iea-dhc.org/the-research/annexes/2011-2014-annex-x/annex-x-project-03.html
Danish Standard 2013	DS 439 Code for practice for domestic water supply installations, Danish Standard.
Dansk Fjernvarme 2011	Benchmark Statistics 2010/2011, 2011.
Dansk Fjernvarme 2014	Benchmark Statistics 2013/2014, 2014. http://www.danskfjernvarme.dk/viden-om/aarsstatistik/benchmarking-statistik-2013-2014
DIN 2003	DIN 4747-1: Fernwärmeanlagen Teil 1: Sicherheitstechnische Ausrüstung von Unterstationen, Hausstationen und Hausanlagen zum Anschluss an Heizwasser-Fernwärmenetze (*Heating plants for district heating Part 1:*

Safety requirements for domestic substations, stations and domestic systems to be connected to hot-water district heating networks); DIN Deutsches Institut für Normung e.V., November 2003

DREWAG 2009 — B. Lehmann, Risikominimierung / Planungssicherheit für Instandhaltungsbudget am Beispiel von Faltenrohrbögen für Fernwärmeleitungen, DREWAG 2009 www.netinform.de/GW/files/pdf/Anlagenforum_Drewag.pdf

Ecoheatcool 2006 — *ECOHEATCOOL Work package 1, The European Heat Market, Final Report* (2006). Intelligent Energy Europe. http://www.euroheat.org/Files/Filer/ecoheatcool/documents/Ecoheatcool_WP1_Web.pdf

EcoHeat4Cities 2012 — Assessment of DHC baseline and improvement potential. Technical report (2012) http://ecoheat4cities.eu/en/upload/Extranet/WP2_Methodology/Ecoheat4cities_Improvement%20potential_Baseline%20study_20111212.pdf

EnEff Stadt 2016a — EnEff Stadt, *Heat from pit water in Bochum-Werne*. Website: http://www.eneff-stadt.info/en/heatingcooling-networks/project/details/heat-from-pit-water-in-bochum-werne/

EnEff Stadt 2016b — EnEff Stadt, *Geothermal use of pit water for local heating supply* (Zwickau). Website: http://www.eneff-stadt.info/en/heatingcooling-networks/project/details/geothermal-use-of-pit-water-for-local-heating-supply/

EnEff Stadt 2016c — EnEff Stadt, LowExTra – *Low-exergy transmission pipes for storing and and distributing heat.* Website: http://www.eneff-stadt.info/en/pdf/heatingcooling-networks/project/details/lowextra-low-exergy-transmission-pipes-for-storing-and-distributing-heat/

EPISCOPE 2014 — EPISCOPE (last updated 02.09.2014): *Statistics of the Building Typology of different European countries,* Intelligent

	Energy Europe. http://episcope.eu/building-typology/country/fr/ and http://episcope.eu/building-typology/country/gb/
Euroheat & Power 2008	Euroheat & Power. *Guidelines for district heating substations*. Prepared by Task Force Customer Installations. Brussels 2008.
Felsmann 2010	Felsmann, C.; Rühling, K. et al: *LowEx Fernwärme - Multilevel District Heating*; Final report, Technische Universität Dresden 2010; FKZ 0327400B
Fiedler 2012	Fiedler/Steitz (http://www.tkda.com): *Optimization of district heating systems steam vs. hot water*, 2012; http://www.asaie.army.mil/Public/ES/netzero/docs/3_District_Heating_Systems_Alternatives_Lederer_Fiedler_01_19_2012.pdf
Fjordvarme 2016	Fjordvarme, Oppvarming og kjöling med fjordvarme på Nordfjordeid (Heating and cooling with fjord-heat at Nordfjordeid). Website: http://www.fjordvarme.no/upload/bruker/dokumenter/presentasjonar/Pres_Fjordvarme.pdf
FLEXYNETS 2015	FLEXYNETS, *Fifth generation, low temperature, high exergy district heating and cooling networks.* H2020 project between 2015 and 2018. http://www.flexynets.eu/en/Home
Frederiksen et al 2013	Frederiksen, S.; Werner, S. (2013): *District heating and cooling*. Studentlitteratur, Lund.
Gadd 2014	Gadd, H. (2014): *To analyse measurements is to know – Analysis of hourly meter readings in district heating systems.* PhD thesis, Department of Energy Sciences, Lund.
Gadd et al 2015	Gadd, H. & Werner, S. (2015): *Fault detection in district heating substations*. Applied Energy 157(2015) 51-59.

Gong et al 2015	Gong, M. & Werner, S. (2015): *Exergy analysis of network temperature levels in Swedish and Danish district heating systems*. Renewable Energy, 84(2015) 106-113.
Gummerus 1989	Gummerus, P., Analys av konventionella abonnentcentraler i fjärrvärmesystem (Analysis of conventional substations in district heating systems). PhD thesis, Chalmers University of Technology, Göteborg 1989.
Hansen 2012	Jens O. Hansen: *Lessons from the Capital of CHP / district energy: COPENHAGEN*, 2012 http://www.districtenergy.org/assets/pdfs/2012CHP-Texas/C2.2HansenJensOleCOWIOctober2012.pdf
HOFOR 2013	HOFOR (2013). *Fra damp til vand.* Information brochure to steam customers in Copenhagen.
ISO 2004	ISO 15927-5 *Hygrothermal performance of buildings. Calculation and presentation of climatic data. Data for design heat load for space heating* (2004). International standard.
Jacob 2003	Andrew Jacob: *A Tale of the New York City Steam System.* 94th Annual International District Energy Association (IDEA) Conference "The Energy Is Building", Philadelphia PA, June 22-25 2003 http://www.districtenergy.org/pdfs/03AnnConfPresen/JacobsNYSteamSystem.pdf
Jangsten M. 2016	*Survey of radiator temperatures in buildings supplied by district heating,* Masters thesis, Chalmers University of Technology.
Johanssson et al 2010	Johansson, P-O., Wollerstrand, J., *Heat output form space heating radiator with add-on-fan blowers,* Proceedings of the COMSOL conference 2010, Paris.
Karlsson 2008	*Self-regulating floor heating systems in low-energy buildings*, 8th Symposium on Building Physics in the Nordic Countries

Laufkötter 2012 — Laufkötter, S. (2012). *Conversion of steam network – Mission Accomplished: Salzburg AG now Heats with Warm Water.* Euroheat & Power (eng) 9(2012):2, 16-20.

Lehtmets 2003 — *Utilization of cold district heating (Nyttiggörande av kall fjärrvärme).* Swedish District Heating Association, Heat Sparse Report 2003:6.

Liao 2005 — Liao, Z., Swainson, M., Dexter, A.L., (2005). *On the control of heating systems in the UK.* Building and Environment 40 (2005), 343-351.

Lund et al 2014 — Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, JE., Hvelplund, F., Mathiesen, BV, *4th Generation District Heating (4GDH) - Integrating smart thermal grids into future sustainable energy systems*. Energy 68(2014) 1-11.

Mermoud et al. 2012 — Mermoud, F.; Khoury, J.; Lachal, B. (2012): *Suivi énergétique du bâtiment 40-42 de l'avenue du Gros Chêne à Onex (GE), rénové selon le standard MINERGIE*. Collection Terre&Environnement Vol. 109. http://archive-ouverte.unige.ch/unige:23005

Mermoud et al. 2014 — Mermoud, F.; Fraga, C.; Hollmuller, P.; Pampaloni, E.; Lachal, B. (2014): *COP5 : Source froide solaire pour pompe à chaleur avec un COP annuel de 5 généralisable dans le neuf et la rénovation.* Collection Terre&Environnement Vol. 126. http://archive-ouverte.unige.ch/unige:35401

Olsen et al. 2014 — Olsen, P.,Christiansen, C., Hofmeister, M., Svendsen, S., Dalla Rosa. A., Thorsen, J-E., Gudmundsson, O., Brand, M., *Guidelines for low-temperature district heating,* EUDP 2010-II: Full scale demonstration of low-temperature district heating in existing buildings, 2014

Persson et al 2011 — Persson, U., Werner, S. (2011). *Heat distribution and the future competitiveness of district heating.* Applied Energy 88(2011) 68-576.

Petersson 2012	Petersson, S., *Personal communication*. FVB Sweden 2012.
Pierce 2007	Pierce, M. (2007). *From Steam to Hot Water and CHP : University of Rochester converts.* District Energy 93(2007):3, 18-22.
Quiquerez et al. 2013	Quiquerez, L.; Cabrera, D.; Lachal, B.; Hollmuller, P. (2013): *Températures de distribution de chauffage du parc immobilier genevois. Etat des lieux et évaluation du potentiel d'optimisation à partir de mesures in situ sur un échantillon de bâtiments.* Université de Genève, http://archive-ouverte.unige.ch/unige:27989
Schwarzfeld 2015	Schwarzfeld, B., Peters, M., Langer, F., *Low-temperature Solar District Heating with Ice Storage and Absorption Heat Pump*. Euroheat & Power (eng) 12(2015):4, 36-39.
Semhach 2002	Semhach, *Principe de fonctionnement en cascade du reseau de Chevilly-Larue et L'Hay Les Roses.* Website : http://semhach.fr/ressdoc/94D30069-5056-9C00-41B805DF0EC1E07B.pdf
Semhach 2011	Semhach, *Plan du réseau de chaleur de la SEMHACH*. Website : http://semhach.fr/ressdoc/B23812F4-5056-9C00-41C6370733BAC821.pdf
SIA 2009	*Installations de chauffage dans les bâtiments – Bases générales et performances requises* (2009). Swiss standard SIA 384/1, Société suisse des ingénieurs et des architectes, Bern
SIA 2011	*Installations d'eau chaude sanitaire dans les bâtiments – Bases générales et performances requises* (2011). Swiss standard SIA 385/1, Société suisse des ingénieurs et des architectes, Bern
Skagestad et al. 2002	Skagestad, B.; Mildenstein, P. (2002): *District Heating and Cooling Connection Handbook.* International Energy Agency.

http://www.districtenergy.org/assets/CDEA/Best-Practice/IEA-District-Heating-and-Cooling-Connection-Handbook.pdf

Spurr 2012 — Spurr, M. (2005): Getting Into Hot Water: Costs and Benefits; nternational District Energy Association Annual Conference June 2012. http://www.districtenergy.org/assets/pdfs/03AnnualConference/Monday-B/B5-1SPURRFVBGetting-into-Hot-Water-IDEA-June-2012-FINAL-2.pdf

Stadtmüller 2004 — Stadtmüller, H. (2004). *Damptnetzumstellung in München – Erfahrungen aus der ersten Umstellphase*. Euroheat & Power 33(2004):1/2, 38-43

Stadtmüller 2006 — Stadtmüller, H. (2006). *Damptnetzumstellung in München – Optimiertes Sasnierungs- und Erneuerungskonzept.* Euroheat & Power 35(2006):11, 30-33

Stene 1995 — Stene, J., Eggen, G., *Heat pump system with distribution at intermediate temperature at the University of Bergen*. Proceedings 19th International Congress of Refrigeration, volume 4b, 1262-1269. The Hague 1995.

St.Paul 2007 — DISTRICT ENERGY ST. PAUL: *Achieving Energy Independence*, 2007 http://www.districtenergy.org/assets/CDEA/Case-Studies/StPaulDistrict-Energy6-27-07.pdf

St.Paul 2016 — https://www.stpaul.gov/departments/mayors-office/sustainable-saint-paul/district-energy-saint-paul

Summerheat 2009 — *SUMMERHEAT, Meeting cooling demands in SUMMER by applying HEAT from cogeneration, Publishable Report* (2009). Intelligent Energy Europe. https://ec.europa.eu/energy/intelligent/projects/sites/iee-projects/files/projects/documents/summerheat_publishable_final_report_en.pdf

Thorsen 2015	Thermal length of heat exchangers for the next generation of DH substations, International conference on Smart Energy systems and 4th Generation District Heating, Copenhagen, August 2015
UNEP 2015	United Nations Environment Programme (UNEP): DISTRICT ENERGY IN CITIES. Unlocking the Potential of Energy Efficiency and Renewable Energy, 2015. http://unep.org/energy/portals/50177/Documents/DistrictEnergyReportBook.pdf
UNEP Paris 2015	United Nations Environment Programme (UNEP): District Energy in Cities. Paris Case Study, 2015. http://districtenergyinitiative.org/case-studies/PARIS-CASE-STUDY.pdf
Vancouver 2015a	City of Vancouver: *2020 ACTION PLAN PART TWO: 2015-2020* http://vancouver.ca/files/cov/greenest-city-2020-action-plan-2015-2020.pdf
Vancouver 2015b	City of Vancouver: *Renewable City Strategy (RCS)*, http://vancouver.ca/files/cov/renewable-city-strategy-2015.pdf
Verhoeven 2014	Verhoeven, R., Willems, E., Harcouët-Menou, V., De Boever, E., Hiddes, L, Op't Veld, P., Demollin, E. *Minewater 2.0 Project in Heerlen the Netherlands: Transformation of a Geothermal Mine Water Pilot Project into a Full Scale Hybrid Sustainable Energy Infrastructure for Heating and Cooling.* Energy Procedia, Volume 46, 2014, Pages 58-67
Wiener Stadtwerke 2016	Wiener Stadtwerke, *Leitungsnetze*. Website: http://www.nachhaltigkeit.wienerstadtwerke.at/daseinsvorsorge/energieversorgung/leitungsnetze.html
Woods et al 1999	Woods, P. et al, *Optimisation of operating temperatures an appraisal of the benefits of low temperature district heating.* Report 1999:T1. IEA-DHC program, Annex V.

Yang et al 2016	Yang, X., Li, H., Svendsen, S., *Modelling and multi-scenario analysis for electric heat tracing system combined with low temperature district heating for domestic hot water supply*. Building Simulation, Volume 9, Page 141-151, 2016.
Yang et al 2016	Yang, X., Li, H., Svendsen, S., *Evaluations of different domestic hot water preparing methods with ultra-low-temperature district heating,* Energy, Volume 109, page 248-259
Zgraggen 2010	Zgraggen, J.M. (2010): *Bâtiments résidentiels locatifs à haute performance énergétique: objectifs et réalités.* Collection Terre&Environnement Vol. 97. https://archive-ouverte.unige.ch/unige:13093
Zhivov 2006	Zhivov, A.E. et al., *Evaluation of European District Heating Systems for Application to Army Installations in the United States.* US Army Corps of Engineers, 2006 http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA461391
Zinko et al 2005	Zinko, H. et al, *Improvement of operational temperature differences in district heating systems*. Report 2005:8DHC-05.03. IEA-DHC program, Annex VIII.
Zvingilaite 2012	Zvingilaite, E., Ommen, T, Elmegaard, B., Franck, ML, *Low temperature district heating consumer unit with micro heat pump for domestic hot water preparation.* 13th International Symposium on District Heating and Cooling, Copenhagen 2012.

Appendix A Survey

IEA-DHC ANNEX XI TRANSFORMATION ROADMAP FROM HIGH TO LOW TEMPERATURE DISTRICT HEATING SYSTEM: SURVEY

We would be very grateful if you would take part in this important survey for an IEA-DHC Annex XI project "*Transformation Roadmap from High to Low Temperature District Heating System*". This project aims to examine whether current district heating networks could function at a lower temperature regime. Consequently, as part of the work, we are collecting information on actual temperature levels required by the customers connected. All the answers you will provide will be kept confidential and will not be shared with any external party. Only the researchers involved in this study will see your responses.

GENERAL INFORMATION

The following tables are concerned with general details about yourself and the district heating project.

ABOUT YOU

Please insert your contact details below.

Surname, Name:	
Company:	
Job Title:	
Email:	
Telephone:	

ABOUT THE DISTRICT HEATING

Please insert general information about the district heating project.

Name:	
Location:	
In operation since:	

ABOUT THE CUSTOMER(S)

Please specify with √ the type of buildings on your network and year of construction/refurbishment.

Customers' type	**New**	**Existing**	**Refurbished**
[ ] Residential Buildings	[ ] Year:	[ ] Year:	[ ] Year:
[ ] Retail /Commercial Buildings	[ ] Year:	[ ] Year:	[ ] Year:
[ ] Institutional Buildings	[ ] Year:	[ ] Year:	[ ] Year:
[ ] Industrial Buildings	[ ] Year:	[ ] Year:	[ ] Year:

DEMAND TYPES

The following tables are concerned with the types of customers connected to the district heating and their requirements. We have considered four demand types (residential, retail/commercial, institutional (e.g. Education, Health, Public buildings) and industrial.
Below are four sections, one for each customer type. For one or more types of customers connected to the district heating network, please select the relevant section and complete the survey to the best of your knowledge.

DEMAND OF RESIDENTIAL CUSTOMERS

Application

Please tick ([√]) where appropriate (you can mark more than one) and add the design temperature required by the customers.

Demand Type	Design Temperature (°C)
[ ] Space Heating	
[ ] Domestic Hot Water	
[ ] Cooling	
[ ] Other (Please specify):	

Customers' Interface

Please tick ([√]) where appropriate and add corresponding typical temperatures at district heating (primary) side of substation.

Interface	Temperatures (°C)			
	Winter		Summer	
	Flow	Return	Flow	Return
[ ] Direct Connection				
[ ] Indirect (Parallel) Connection				

Customers' heating system

Please tick ([√]) where appropriate and add corresponding typical temperatures required.

Heating Type	Flow Temperature (°C)	Return Temperature (°C)
[ ] Radiators		
[ ] Underfloor Heating		
[ ] Wall/Ceiling Radiant Panels		
[ ] Air Handling Unit Coils		
[ ] Terminal Unit Coils		
[ ] Heat Pumps		
[ ] Absorption Chillers		
[ ] Other (Please specify):		

Please tick ([√]) where appropriate.

Is night time setback used?	[ ] Yes	[ ] No	[ ] Unknown

Customers' domestic hot water system

Please tick ([√]) where appropriate and add corresponding typical temperatures required.

Domestic Hot Water	Flow Temperature (°C)	Flow Temperature (°C)
[ ] With Storage Tank/Heat Exchanger (customers' side)		
[ ] With Storage Tank/Heat Exchanger (district heating side)		

[ ] No storage tank		

Demand Of Retail/Commercial Customers

Application

Please tick ([√]) where appropriate (you can mark more than one) and add the design temperature required by the customers.

Demand Type	**Design Temperature (°C)**
[ ] Space Heating	
[ ] Domestic Hot Water	
[ ] Cooling	
[ ] Other (Please specify):	

Customers' Interface

Please tick ([√]) where appropriate and add corresponding typical temperatures at district heating (primary) side of substation.

Interface	**Temperatures (°C)**			
	Winter		**Summer**	
	Flow	Return	Flow	Return
[ ] Direct Connection				
[ ] Indirect (Parallel) Connection				

Customers' heating system

Please tick ([√]) where appropriate and add corresponding typical temperatures required.

Heating Type	**Flow Temperature (°C)**	**Return Temperature (°C)**
[ ] Radiators		
[ ] Underfloor Heating		
[ ] Wall/Ceiling Radiant Panels		
[ ] Air Handling Unit Coils		
[ ] Terminal Unit Coils		
[ ] Heat Pumps		
[ ] Absorption Chillers		
[ ] Other (Please specify):		

Please tick ([√]) where appropriate.

Is night time setback used?	[ ] Yes	[ ] No	[ ] Unknown

Customers' domestic hot water system

Please tick ([√]) where appropriate and add corresponding typical temperatures required.

Domestic Hot Water	**Flow Temperature (°C)**	**Flow Temperature (°C)**
[ ] With Storage Tank/Heat Exchanger (customers' side)		
[ ] With Storage Tank/Heat Exchanger (district heating side)		
[ ] No storage tank		

Demand Of Institutional Customers

Please specify Type (e.g. Educational, Health, Public Buildings etc.)

Application

Please tick ([√]) where appropriate (you can mark more than one) and add the design temperature required by the customers

Demand Type	**Design Temperature (°C)**
[ ] Space Heating	
[ ] Domestic Hot Water	
[ ] Cooling	
[ ] Other (Please specify):	

Customers' Interface

Please tick ([√]) where appropriate and add corresponding typical temperatures at district heating (primary) side of substation.

Interface	**Temperatures (°C)**			
	Winter		**Summer**	
	Flow	Return	Flow	Return
[ ] Direct Connection				
[ ] Indirect (Parallel) Connection				

Customers' heating system

Please tick ([√]) where appropriate and add corresponding typical temperatures required.

Heating Type	**Flow Temperature (°C)**	**Return Temperature (°C)**
[ ] Radiators		
[ ] Underfloor Heating		
[ ] Wall/Ceiling Radiant Panels		
[ ] Air Handling Unit Coils		
[ ] Terminal Unit Coils		
[ ] Heat Pumps		
[ ] Absorption Chillers		
[ ] Other (Please specify):		

Please tick ([√]) where appropriate.

Is night time setback used?	[ ] Yes	[ ] No	[ ] Unknown

Customers' domestic hot water system

Please tick ([√]) where appropriate and add corresponding typical temperatures required.

Domestic Hot Water	**Flow Temperature (°C)**	**Flow Temperature (°C)**
[ ] With Storage Tank/Heat Exchanger (customers' side)		
[ ] With Storage Tank/Heat Exchanger (district heating side)		
[ ] No storage tank		

Demand Of Industrial Customers

Please specify Type (e.g. Educational, Health, Public Buildings etc.)

Application

Please tick ([√]) where appropriate (you can mark more than one) and add the design temperature required by the customers

Demand Type	Design Temperature (°C)
[ ] Space Heating	
[ ] Domestic Hot Water	
[ ] Process/Industrial Heating Please specify:	
[ ] Cooling	
[ ] Other (Please specify):	

Customers' Interface

Please tick ([√]) where appropriate and add corresponding typical temperatures at district heating (primary) side of substation.

Interface	Temperatures (°C)			
	Winter		Summer	
	Flow	Return	Flow	Return
[ ] Direct Connection				
[ ] Indirect (Parallel) Connection				

Customers' heating system

Please tick ([√]) where appropriate and add corresponding typical temperatures required.

Heating Type	Flow Temperature (°C)	Return Temperature (°C)
[ ] Radiators		
[ ] Underfloor Heating		
[ ] Wall/Ceiling Radiant Panels		
[ ] Air Handling Unit Coils		
[ ] Terminal Unit Coils		
[ ] Heat Pumps		
[ ] Absorption Chillers		
[ ] Other (Please specify):		

Please tick ([√]) where appropriate.

Is night time setback used?	[ ] Yes	[ ] No	[ ] Unknown

Customers' domestic hot water system

Please tick ([√]) where appropriate and add corresponding typical temperatures required.

Domestic Hot Water	Flow Temperature (°C)	Flow Temperature (°C)
[ ] With Storage Tank/Heat Exchanger (customers' side)		
[ ] With Storage Tank/Heat Exchanger (district heating side)		
[ ] No storage tank		

TEMPERATURE LEVELS OUTLOOK

The following questions concern the potential for reduction of the current temperature levels (flow and return) in customers' heating systems. Please answer the questions below.

What are the factors that have informed the choice of supply temperature?	
Has the prospect of reducing the supply temperatures been considered/discussed?	
Is there, in your opinion, scope for reducing the supply temperature for customer heating systems?	
To what extent do you think is possible to lower the supply temperature for the system and still maintain the required customer temperature?	
What are the barriers that prevent the reduction of supply temperature levels from being implemented?	

What could be done to remove these barriers?	